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PAPERS IN PRESS FOR FORTHCOMING ISSUES

ORIGIN AND CLASSIFICATION OF SUBMARINE CANYONS. By Ph. H. Kuenen

LIMESTONE WALLS OF OKINAWA. By D. E. Flint, G. Corwin, W. P. Fuller, M. C. Dings, F. S. MacNeil, and R. A. Saplis

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DEFORMATION OF YULE MARBLE

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PART VI—IDENTITY AND SIGNIFICANCE OF DEFORMATION LAMELLAE AND PARTINGS IN CALCITE GRAINS. By Iris Borg and Francis J. Turner

Secretary's Note: Reprints of the two correlation charts will be available *after* November 1. Remittance should accompany order.

Correlation of Triassic formations of Canada. By F. H. McLearn *25 cents*

Correlation of the Jurassic of Canada. By Hans Frebold *25 cents*

Reprints of ***Bibliography and Index of Literature on Uranium and Thorium and Radioactive Occurrences in U. S., Part 2*** (p. 1103–1172 of this issue) are available at *25 cents* per copy.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 64, PP. 1103-1172 OCTOBER 1953

BIBLIOGRAPHY AND INDEX OF LITERATURE ON URANIUM AND THORIUM AND RADIOACTIVE OCCURRENCES IN THE UNITED STATES

PART 2: CALIFORNIA, IDAHO, MONTANA, OREGON, WASHINGTON, AND WYOMING

BY MARGARET COOPER

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FOREWORD

The following bibliography consists of references to published literature, press releases, speeches, and both open-file and other unclassified reports dealing with uranium, thorium, and radioactive occurrences in California, Idaho, Montana, Oregon, Washington, and Wyoming. It is Part 2 of a comprehensive bibliography planned to cover references to all similar deposits throughout the world. While the object has been to make the present bibliography as all-inclusive as possible, from the point of view of including all the major papers and at least one reference to each known radioactive occurrence in these States, only references for which the original text was readily available for examination and checking have been cited at this time. The remaining old and new references will be added to this basic list when the section is ready for inclusion in the comprehensive volumes, planned for future publication as a complete bibliography of the entire United States and world.

The main bibliography consists of an author section, in which each reference has been assigned an individual item number. Following the author listings are the anonymous notes, which are listed in chronological order, and alphabetically by title within each year. The bibliography proper is followed by three indexes: Index I, Gazetteer for California, Idaho, Montana, Oregon, Washington, and Wyoming; Index II, Geographical Index for California, Idaho, Montana, Oregon, Washington, and Wyoming; Index III, Subject Index for California, Idaho, Montana, Oregon, Washington, and Wyoming. The geographical and subject indexes have been made as detailed as practicable since the main reference entries have not been annotated. Where there are variations in spelling or alternate names for the same locality, a standard form has been used in the geographical and subject indexes, and the variations have been noted in the gazetteer. Where county boundary lines have been changed since a reference was written, the locality has been listed under the county in which it is found today.

A fairly extensive survey has been made of the geological and mining literature published through 1949 in compiling the references included in this bibliography. A few of the standard American and English geological and mining publications have also been reviewed up to the early part of 1952. Every reference cited in the bibliography has been checked with the original text. References re-cited from Part 1* of the bibliography, covering Arizona, Nevada,

* Cooper, Margaret, 1953, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States. Part 1: Arizona, Nevada, and New Mexico: Geol. Soc. America Bull., v. 64, p. 197–234.

and New Mexico, have been assigned the same item number as in Part 1. The authors and item numbers of these re-cited references have also been recorded here in regular alphabetical order in the second group of author listings, which gives all the new references on the States covered by this bibliography.

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Snake River: monazite, trace in sands: 11, 240.

Boise County
Fergusonite Occurrences—
Idaho City dredge, Idaho City: in placer sand: 298.
Monazite Occurrences—
General: 0.2–0.3% in stream gravels: 363.
Boise Basin: 78, 82, 194, 247, 290; 250 lbs. per ton: 11; monazite, recovery plant at Boise: 385.
Baumhoff-Marshall operations in Boise Basin: jig concentrates with 2.2% thorium oxide and 0.13% monazite per ton of gravel: 300.
Monazite group of Western Gold Corp.: placers: 349

Centerville: 82, 194, 237, 242, 252, 285, 298; from a trace to 286 lbs. per ton: 11.
Centerville Mining & Milling Co.: lands near Idaho City along Grimes and Quartz Creeks and their tributaries: 328; mill built to recover and clean monazite sand, burned and not rebuilt: 298; operated placers at Centerville on Grimes and Granite Creeks: 326.
Elk Creek placers near Idaho City: to be worked for monazite: 349.
Garden Valley: 32 lbs. per ton: 11.
Grimes Creek near Centerville: from a trace to 358 lbs. per ton: 11.
Idaho Basin: 197, 259, 260, 298.
Idaho City: 78, 82, 194, 252, 298; 42 lbs. per ton: 11; from lake beds: 259.
Idaho City Mining District: 241.
Quartzburg Mining District: 241.
Junction of Moore and Granite Creeks 3 mi. E of Idaho City: 298; in gravel bench carrying about 1.20% thoria: 260.
Marsh: 38 lbs. per ton: 11.
Moore Creek Mining District: 241.
Placerville: 78, 82; 36 to 170 lbs. per ton: 11.
Poncia placer tract in Swede Gulch near center of S. 9, T. 7 N., R. 5 E., 1½ mi. SE of Pioneerville: with polycrase in heavy sand: 298.
Red Fox claim, Centerville Mining District: 30 and 224 lbs. per ton: 11.
Wolf Creek near Centerville: in alluvial gold washings: 260.
Wolf Creek near Placerville: from alluvial gold washings: 259.
Monazite Production—
Centerville Mining & Milling Co.: operated monazite placers at Centerville on Grimes and Granite Creeks: 326.
Polycrase Occurrences—
Centerville: 298.
Poncia placer tract in Swede Gulch near center of S. 9, T. 7 N., R. 5 E., 1½ mi. SE of Pioneerville: 298.
Samarskite Occurrences—
Boise Basin: 194.
Idaho City: 194.
Idaho City dredge, Idaho City: in heavy concentrate: 298.
Thorium Occurrences—
General: 0.2–0.3% monazite in stream gravels: 363.
Boise Basin: monazite: 78, 82, 247, 290; monazite, 250 lbs. per ton: 11; monazite; recovery plant at Boise: 385; monazite, samarskite: 194.
Baumhoff-Marshall operations in Boise Basin: monazite in jig concentrates showed 2.2% thorium oxide and 0.13% monazite per ton of gravel: 300.
Monazite group of Western Gold Corp.: monazite placers: 349.
Centerville: monazite: 82, 194, 237, 242, 252, 285; monazite, from a trace to 286 lbs. per ton: 11; monazite in gold placers: 298; polycrase in placer concentrate: 298.
Centerville Mining and Milling Co.: lands near Idaho City along Grimes and Quartz Creeks and their tributaries; monazite: 328; mill built to recover and clean monazite sand, burned and not rebuilt: 298; operated placers at Centerville on Grimes and Granite Creeks; monazite: 326; methods of mining and concentration: 326.
Elk Creek placers near Idaho City: to be worked for monazite: 349.
Garden Valley: monazite, 32 lbs. per ton: 11.
Grimes Creek near Centerville: monazite, from a trace to 358 lbs. per ton: 11.
Idaho Basin: monazite: 197, 259, 260; monazite with gold in placers: 298.
Idaho City: monazite: 78, 82, 252; monazite, 42 lbs. per ton: 11; monazite from lake beds: 259; monazite, samarskite: 194, 298.
Idaho City dredge, Idaho City: samarskite in heavy concentrate: 298.
Idaho City Mining District: monazite: 241.
Quartzburg Mining District: monazite: 241.
Junction of Moore and Granite Creeks 3 mi. E. of Idaho City: monazite in gravel bench carrying about 1.20% thoria: 260; monazite in sandy lake beds forming false bedrock in gravel bench: 298.
Marsh: monazite, 38 lbs. per ton: 11.
Moore Creek Mining District: monazite: 241.
Placerville: monazite: 78, 82; monazite, 36 to 170 lbs. per ton: 11.
Poncia placer tract in Swede Gulch near center of S. 9, T. 7 N., R. 5 E., 1½ mi. SE of Pioneerville: polycrase with monazite in heavy sand: 298.
Red Fox Claim, Centerville Mining District: monazite, 30 and 224 lbs. per ton: 11.
Wolf Creek near Centerville: monazite in alluvial gold washings: 260.
Wolf Creek near Placerville: monazite from alluvial gold washing: 259.
Uranium Occurrences—
Boise Basin: monazite, samarskite: 194.
Carterville: uranophane: 82.
Centerville: polycrase in placer concentrate: 298.
Centerville in Idaho Basin: uranophane: 298.
Idaho City: monazite, samarskite: 194.
Idaho City dredge, Idaho City: fergusonite in placer sand: 298; samarskite in heavy concentrate: 298.
Poncia placer tract in Swede Gulch near center of S. 9, T.7N., R.5E., 1½ mi. SE of Pioneerville: polycrase with monazite in heavy sands: 298.
Uranophane Occurrences—
Carterville: 82.
Centerville in Idaho Basin: 298.

Bonner County
Thorium Occurrences—
Pend Oreille Mining District
Lake Pend Oreille area:
Bayview granodiorite: allanite: 230; geology. 230; mineralization: 230; mineralogy: 230; petrography: 230.
Granite Creek granodiorite: allanite: 230; geology: 230; mineralization: 230; mineralogy: 230; petrography: 230.

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Packsaddle Mountain granodiorite: allanite: 230; geology: 230; mineralization: 230; mineralogy: 230; petrography: 230.

Brannerite Occurrences
See under individual county names and under Index III, Brannerite Occurrences—Idaho: 2, 238, 239, 298, 316.

Canyon County
Monazite Occurrences—
Payette River: 6 lbs. per ton: 11.
Thorium Occurrences—
Payette River: monazite, 6 lbs. per ton: 11.

Carnotite Occurrences
See under individual county names and under Index III, Carnotite Occurrences—Idaho: 53.

Clearwater County
Monazite Occurrences—
Dent: 78, 82, 217; 126 to 283 lbs. per ton: 11.
Little John claim, Gold Run Creek: 295.
Musselshell Creek: 193, 290, 298.
Musselshell Creek, 28 mi. E of Greer and 10 mi. from Weippe: 82, 295.
Musselshell Creek (Weippe) Mining District: 241.
North Fork Clearwater River: 193; 46 lbs. per ton: 11.
Orofino: 78, 82, 104; 6 to 88 lbs. per ton: 11.
Pierce: 193, 290; from a trace to 94 lbs. per ton: 11.
Pierce, Cow Creek: 46 to 81 lbs. per ton: 11.
Pierce Mining District: 298; 70 lbs. per ton: 11.
Rhodes Creek: trace: 11.
Thorium Occurrences—
Dent: monazite: 78, 82, 217; monazite, 126 to 283 lbs. per ton: 11.
Little John claim, Gold Run Creek: monazite, best prospect in area: 295.
Musselshell Creek: monazite: 193, 290; monazite in gold placers: 298; monazite samples cleaned to 90% or usual commercial grade averaged 3% thoria: 298.
Musselshell Creek, 28 mi. E of Greer and 10 mi. from Weippe: monazite: 82, 295.
Musselshell Creek (Weippe) Mining District: monazite: 241.
North Fork Clearwater River: monazite: 193; monazite, 46 lbs. per ton: 11.
Orofino Region
Along Clearwater River between Ahsaka and Peck station: allanite, 246; geology, 246; mineralization, 246; mineralogy, 246; petrography: 246.
Along North Fork Clearwater River N. of mouth of Freeman Creek: allanite, 246; geology, 246; mineralization, 246; mineralogy, 246; petrography: 246.
Along Orofino Creek, E. of mouth of Whiskey Creek, gneissic rocks: allanite, 246; geology, 246; mineralization, 246; mineralogy, 246; petrography: 246.
Idaho Batholith SE of Orofino: allanite: 246.
Orofino: monazite: 78, 82; monazite in gold placers: 104; monazite, 6 to 88 lbs. per ton: 11.
Pierce: monazite: 193, 290; monazite, from a trace to 94 lbs. per ton: 11.
Pierce, Cow Creek: monazite, 46 to 81 lbs. per ton: 11.
Pierce Mining District: monazite, 70 lbs. per ton: 11; monazite in concentrates: 298.
Rhodes Creek: monazite, trace: 11.

Custer County
Brannerite Occurences—
Kelly Gulch, Stanley Basin: 238, 239, 316.
Stanley Basin near head of Kelly Gulch in placer worked by Henry Sturkey: 298.
Euxenite Occurences—
Kelly Gulch, Stanley Basin: placer mine: 196.
Stanley Basin near head of Kelly Gulch in placer worked by Henry Sturkey: 298.
Thorium Occurrences—
Kelly Gulch, Stanley Basin: brannerite: 239, 316; brannerite in placers: 238; placer mine, euxenite: 196.
Stanley Basin near head of Kelly Gulch in placer worked by Henry Sturkey: brannerite with gold; euxenite: 298.
Uranium Occurrences—
Kelly Gulch, Stanley Basin: brannerite: 238, 239, 316; placer mine, euxenite: 196.
Stanley Basin near head of Kelly Gulch in placer worked by Henry Sturkey: brannerite with gold; euxenite: 298.

Elmore County
Thorium Occurrences—
Rocky Bar Mining District
Idaho Batholith: allanite: 191.

Euxenite Occurrences
See under individual county names and under Index III, Euxenite Occurrences—Idaho: 196, 298.

Fergusonite Occurrences
See under individual county names and under Index III, Fergusonite Occurrences—Idaho: 298.

Idaho County
Monazite Occurrences—
General: 0.2–0.3% in stream gravels: 363.
Baker Gulch, Crooked River: 320 lbs. per ton: 11.
Camp Howard Mining District: trace: 11.
Davis Mining Co. property between Secesh River and Lower Ruby Creek: in placers: 208.
Elk City: 26 to 108 lbs. per ton: 11.
Elk City Mining District: 6 to 808 lbs. per ton: 11.
Florence Mining District
Florence: trace: 11.
Grouse Creek: 284.
Lake Creek: 208.
Marshall Lake District: 376 lbs. per ton: 11.
Middle Fork Clearwater River: 193.
Northern Part: 290.
Resort: 112 lbs. per ton: 11.
Ruby Creek: 208.
South Fork Mining & Leasing Co., Buffalo Gulch near Elk City: 374.
Syringa: trace: 11.
Tyee Mining Co. near Elk City: low content: 300.

Warren Mining District: 82.
Ruby placers: high content: 300.
Warren Basin: 197.
Warren Creek: 372.
Warren Meadows: with uraninite: 285.
Thorium Occurrences—
General: 0.2–0.3% monazite in stream gravels: 363
Baker Gulch, Crooked River: monazite, 320 lbs. per ton: 11.
Camp Howard Mining District: monazite, trace: 11.
Davis Mining Co. property between Secesh River and Lower Ruby Creek: monazite in placers: 208.
Elk City: monazite, 26 to 108 lbs. per ton: 11.
Elk City Mining District: monazite, 6 to 808 lbs. per ton: 11.
Florence Mining District
General: allanite: 284.
Florence: monazite, trace: 11.
Grouse Creek: monazite: 284.
Lake Creek: monazite: 208.
Marshall Lake district: monazite, 376 lbs. per ton: 11.
Middle Fork Clearwater River: monazite: 193.
Northern Part: monazite: 290.
Resort: monazite, 112 lbs. per ton: 11.
Ruby Creek: monazite: 208.
South Fork Mining & Leasing Co., Buffalo Gulch near Elk City: monazite: 374.
Syringa: monazite, trace: 11.
Tyee Mining Co. near Elk City: low in monazite: 300.
Warren Mining District: monazite: 82.
Buck Placer, Houston Creek: uraninite: 285.
Ruby placers: high in monazite: 300.
Warren Basin: monazite: 197.
Warren Creek: monazite: 372.
Warren Meadows: monazite, ThO_2 percentage given; uraninite: 285.
Uraninite Occurrences—
Warren Mining District
Buck Placer, Houston Creek: 285.
Warren Meadows: 285.
Uranium Occurrences—
General: uranium oxide with 15–60% uranium in Upper Cretaceous sandstone: 333.
Knob Hill, Orogrande: uranium and molybdenite: 332.
Warren Mining District
Buck Placer, Houston Creek: uraninite: 285.
Warren Meadows: uraninite: 285.

Latah County
Autunite Occurrences—
Avon, 3–6 mi. N. of: questionable occurrence: 190.
Last Chance mine, Avon Mica district: with metatorbernite: 301.
Meta-torbernite Occurrences—
Last Chance mine, Avon Mica district: with autunite: 301.
Uranium Occurrences—
Avon, 3–6 mi. N. of, mica pegmatites: autunite(?): 190; geographic features: 190; geology: 190; mineralogy: 190; wall rock alteration: 190.
Last Chance mine, Avon Mica district, 3 mi. N of Avon and 23 mi. NE of Moscow: autunite, meta-torbernite in pegmatite: 301; geology: 301.

Lemhi County
Monazite Occurrences—
Leesburg: 78, 82, 217; 20 to 44 lbs. per ton: 11.
Leesburg Basin: .5 to 10 lbs. per ton: 11; placer diggings: 217.
Arnett Creek: 217; .5 lb. per ton: 11.
Richardson Bros. property: 217.
Wards Gulch: 217; 5 lbs. per ton: 11.
Radioactive Areas—
Kentuck mine, N side of Salmon River W of Shoup: low radioactivity; no uranium reported: 311.
Ulysses—Kittie Burton mill on Indian Creek, 4 mi. from main road on Salmon River and 37 mi. by road NW of Salmon: geology; mines and mill not worked; mines inaccessible by car and not visited; no abnormal radioactivity in readings along Indian Creek road nor in crude and ground ore, concentrates, and tailings, no samples taken: 311.
Thorium Occurrences—
Leesburg: monazite: 78, 82, 217; monazite, 20 to 44 lbs. per ton: 11.
Leesburg Basin: monazite, .5 to 10 lbs. per ton: 11; placer diggings, monazite: 217.
Arnett Creek: monazite: 217; monazite, .5 lb. per ton: 11.
Richardson Bros. property: monazite: 217.
Wards Gulch: monazite: 217; monazite, 5 lbs. per ton: 11.
Uranium Occurrences—
Garm-Lemoureaux mine, owned by the estate of Ira Lemoureaux, on Allan Creek, 30 mi. by road N of Salmon: geology: 311; material on dumps contained 0.015–0.13% equivalent uranium and 0.005–0.11% uranium: 311; radioactivity: 311.
Grunter mill owned by Gold Producers, Inc.: mill concentrate contained 0.071% equivalent uranium and 0.043% uranium: 311.
Grunter mine owned by Gold Producers, Inc., on N side of Salmon River W of Shoup: geology: 311; radioactivity: 311; three ore samples contained 0.002–0.01% equivalent uranium and 0.001% uranium: 311.
Road cut, N end Pine Creek bridge, Shoup: chloritic material in fracture, 0.004% equivalent uranium and 0.001% uranium: 311; fracture surface with chlorite (?), 0.01% equivalent uranium: 311; gneiss, 0.01% equivalent uranium: 311; quartz monzonite porphyry, 0.01% equivalent uranium: 311.

Lincoln County
Monazite Occurrences—
Shoshone: 217; 26 lbs. per ton: 11, 240.
Thorium Occurrences—
Shoshone: monazite: 217; monazite, 26 lbs. per ton: 11, 240.

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Meta-torbernite Occurrences
See under individual county names and under Index III, Meta-torbernite Occurrences—Idaho: 301.

Minidoka County
Monazite Occurrences—
Minidoka: 78, 82; 8 lbs. per ton: 11, 240.
Thorium Occurrences—
Minidoka: monazite: 78, 82; monazite, 8 lbs. per ton: 11, 240.

Monazite Occurrences
See under individual county names and under Index III, Thorium Occurrences—Idaho: 11, 78, 82, 104, 193, 194, 197, 207, 208, 212, 217, 237, 240, 241, 242, 247, 252, 259, 260, 283, 284, 285, 290, 295, 298, 299, 300, 306, 326, 327, 328, 349, 357, 358, 363, 364, 366, 368, 371, 372, 374, 385, 387, 391.
Bibliography: 290, 299.

Monazite Processes
See under individual county names and under Index III, Monazite Processes—Idaho: 358, 363, 366, 371.

Monazite Production
See under individual county names and under Index III, Monazite Production—Idaho: 326, 364, 368, 385, 387, 391.

Nez Perce County
Monazite Occurrences—
Lewiston, Clearwater River: 52 lbs. per ton: 11.
Salmon River: 217; trace: 11.
Thorium Occurrences—
Lewiston, Clearwater River: monazite, 52 lbs. per ton: 11.
Salmon River: monazite: 217; monazite, trace: 11.

Owyhee County
Monazite Occurrences—
Oreana: 78, 82; 56 lbs. per ton: 240.
Thorium Occurrences—
Oreana: monazite: 78, 82; monazite, 56 lbs. per ton: 240.

Payette County
Monazite Occurrences—
Payette River: 78, 82.
Thorium Occurrences—
Payette River: monazite: 78, 82.

Phosphates, Uranium-bearing, Occurrences
See under individual county names and under Index III, Phosphates, Uranium-bearing, Occurrences—Idaho: 53, 306.

Pitchblende Occurrences
See under individual county names and under Index III, Pitchblende Occurrences—Idaho: 102, 267.

Polycrase Occurrences
See under individual county names and under Index III, Polycrase Occurrences—Idaho: 298.

Prospectors' Guides
See under individual county names and under Index III, Prospectors' Guides—Idaho: 90.

Radioactive Areas
See under individual county names and under Index III, Radioactive Areas—Idaho: 45, 311.

Radioactive Galena Ores
See under individual county names and under Index III, Radioactive Galena Ores—Idaho: 45.

Samarskite Occurrences
See under individual county names and under Index III, Samarskite Occurrences—Idaho: 194, 298.

Shoshone County
Carnotite Occurrences—
Coeur d'Alene Mining District
Sunshine mine: in Pre-Cambrian Belt series: 53.
Pitchblende Occurrences—
Coeur d'Alene Mining District:
Coeur d'Alene mine: 102.
Sunshine mine: 102, 267.
Radioactive Areas—
Coeur d'Alene Mining District
Sunshine mine
Morningstar vein: galena ores: 45.
Sunshine vein: galena ores: 45.
Tamarack vein: galena ores: 45.
Radioactive Galena Ores—
Coeur d'Alene Mining District
Sunshine mine
Morningstar vein: 45.
Sunshine vein: 45.
Tamarack vein: 45.
Thorium Occurrences—
Coeur d'Alene Mining District:
allanite: 192.
Coeur d'Alene mine: uraninite: 305.
Sunshine mine, Sunshine Mining Co., at Kellogg: uraninite: 305, 367, 373.
Uraninite Occurrences—
Coeur d'Alene Mining District
Coeur d'Alene mine: 288, 305.
Sunshine mine, Sunshine Mining Co., at Kellogg: 251, 288, 305, 367, 373; age determination by lead isotopes: 250; chemical analysis showing 26.9% U_3O_8 and no thorium: 250; in Sunshine vein: 250.
Uranium Occurrences—
Coeur d'Alene Mining District
Coeur d'Alene mine: pitchblende: 102; present uranium exposures marginal in grade: 306; small uranium showing: 306; uraninite: 288, 305.
Sunshine mine, Sunshine Mining Co., at Kellogg: carnotite in Pre-Cambrian Belt series: 53; geology: 251; mineralization: 251; most important known potential uranium source in area: 306; pitchblende: 102, 267; present uranium exposures marginal in grade: 306; uraninite: 251, 288, 305, 367, 373; uraninite, age determination by lead isotopes: 250; uraninite, chemical analysis showing 26.9% U_3O_8 and no thorium: 250; uraninite in Sunshine vein: 250; uranium: 386.

Thorium Occurrences
See under individual county names and under Index III, Thorium Occurrences—Idaho: 11, 78, 82, 104, 189, 191, 192, 193, 194, 196, 197, 207, 208, 212, 217, 230, 237, 238, 239, 240, 241, 242, 246, 247, 249, 252, 259, 260, 283, 284, 285, 290, 295, 298, 299, 300, 305, 306, 316, 326, 327, 328, 349, 357, 358, 363, 364, 366, 367, 368, 371, 372, 373, 374, 385, 387, 391.
Bibliography: 9, 290, 299.

Thorium Production
See under individual county names and under Index III, Thorium Production—Idaho: 385.

Twin Falls County
Uranium Occurrences—
Cedar Creek 20 mi. W. of Rogerson: uranium deposit in a crater carries 1.15% U_3O_8: 336.
Rabbit Springs S. of Twin Falls: uranium in geodes: 266.

Uraninite Occurrences
See under individual county names and under Index III, Uraninite Occurrences—Idaho: 250, 251, 285, 288, 305, 367, 373.

Uranium Occurrences
See under individual county names and under Index III, Uranium Occurrences—Idaho: 2, 53, 82, 102, 190, 194, 196, 238, 239, 250, 251, 266, 267, 285, 288, 290, 298, 301, 305, 306, 311, 316, 332, 333, 336, 367, 373, 386.
Bibliography: 9, 10, 290.

Uranium Prospecting
See under individual county names and under Index III, Uranium Prospecting—Idaho: 90.

Uranophane Occurrences
See under individual county names and under Index III, Uranophane Occurrences—Idaho: 82, 298.

Valley County
Monazite Occurrences—
Big Creek area near Cascade: monazite production: 212.
Big Creek S of Cascade: 371.
Cascade: gravels dredged by Baumhoff-Marshall: 391; in placers and gold tailings: 387.
Lardo: 20 lbs. per ton: 11.
McCall: 357; monazite, treatment process: 366.
Penmans Fork, Big Creek: 528 lbs. per ton: 11.
Rare Earth Minerals Co., McCall: from placers; to ship 16000 t. concentrates in next 10 years: 368.
Monazite Processes—
General: treatment processes: 366.
Monazite Production—
Big Creek area near Cascade: 212.
Cascade: Baumhoff-Marshall to install new, larger dredge for deeper monazite gravels: 391; monazite gravels dredged by Baumhoff-Marshall: 391; placers and gold tailings: 387.
Rare Earth Minerals Co., McCall: to ship 16000 t. concentrates in next 10 years: 368.
Thorium Occurrences—
Big Creek area near Cascade: monazite production: 212.
Big Creek S of Cascade: monazite: 371.
Cascade: monazite gravels dredged by Baumhoff-Marshall: 391; monazite in placers and gold tailings: 387.
Lardo: monazite, 20 lbs. per ton: 11.
McCall: monazite: 357; monazite, treatment process: 366.
Penmans Fork, Big Creek: monazite, 528 lbs. per ton: 11.
Rare Earth Minerals Co., McCall: monazite from placers: 368.
Stibnite, 5 mi. S. of: allanite in pegmatitic rock, radiometric analysis with Geiger counter gave 0.32% Th: 249.

MONTANA
General
Agates, Uranium-bearing, Occurrences—
Yellowstone River basin: 214.
Lignites, Uranium-bearing, Occurrences—
General: 27.
Phosphates, Uranium-bearing, Occurrences—
General: 53.
Low grade uranium ores: 306.
Thorium Occurrences—
General: 12, 25.
Uranium Occurrences—
General: 12, 13, 25, 118.
Lignite, Uranium-bearing: 27.
Phosphates, Uranium-bearing: 53; low grade uranium ores: 306.
Radium ore deposits: 209.
Types: hydrothermal vein deposits: 62.
Yellowstone River Basin: uranium in moss agate: 214.
Uranium Prospecting—
General: 90.

Agates, Uranium-bearing, Occurrences
See under individual county names and under Index III, Agates, Uranium-bearing, Occurrences—
Montana: 214.

Beaverhead County
Pitchblende Occurrences—
Gilmore and Pittsburg Railway between Armstead and Brenner: 331.
Thorium Occurrences—
Gilmore and Pittsburg Railway, 34 mi. from Armstead and 10 mi. from Brenner: pitchblende: 331.
Uranium Occurrences—
Armeson-McKenney property, owned by W. G. Armeson and the Kenney Logging Co., E of the Continental Divide, along upper part of N fork of Frying Pan Creek, 2½ mi. from Lemhi Pass: geology; 311; radioactivity: 311; Trapper No. 1 claim, 200 ft. from discovery pit, 0.023% equivalent uranium, 0.002% uranium: 311; Trapper No. 1 discovery pit, 0.077% equivalent uranium, 0.004% uranium: 311; Trapper No. 4 discovery pit, 0.004–0.35% equivalent uranium, 0.001–0.01% uranium: 311.
Gilmore and Pittsburg Railway, 34 mi. from Armstead and 10 mi. from Brenner· pitchblende: 331.

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Bibliographies
Thorium Occurrences: 9, 312.
Uranium Occurrences: 9, 10, 312.

Carnotite Occurrences
See under individual county names and under Index III, Carnotite Occurrences—Montana: 378.

Fergusonite Occurrences
See under individual county names and under Index III, Fergusonite Occurrences—Montana: 210, 211, 235, 236.

Granite County
Monazite Occurrences—
Little Gold Creek: in gold placers: 262.
Princeton: 78, 82; 6 lbs. per ton: 11.
Thorium Occurrences—
Little Gold Creek: monazite in gold placers: 262.
Princeton: monazite: 78, 82; monazite, 6 lbs. per ton: 11.

Jefferson County
Carnotite Occurrences—
Boulder Mining District
Free Enterprise group, Elkhorn Mining Co., near Boulder: with torbernite: 378.
Meta-torbernite Occurrences—
Basin-Boulder-Clancey area
Jack mine: 286.
Mountain Queen mine: 286.
Pitchblende Occurrences—
Boulder Mining District
Free Enterprise claim, Elkhorn Mining Co., near Boulder: 304, 376, 377.
Radioactive Areas—
Boulder: Sunshine Mining Co. of Kellogg investigating discovery; unnamed radioactive mineral: 365.
Radioactive Occurrences—
Basin-Boulder-Clancey area
Alice claim: slight radioactivity: 286.
Bullion mine 7 mi. N of Basin: radioactivity: 286.
Carbonate claim: slight radioactivity: 286.
Comstock group: radioactivity: 286.
Gold Point claim: secondary uranium minerals: 286.
King Solomon mine: slight radioactivity: 286.
Liverpool mine N side of Lump Gulch, 2 mi. N of Clancey: radioactivity: 286.
Lone Eagle mine near head of Quartz Creek: radioactivity: 286.
Nickelodeon claim S of Boulder: radioactivity: 286.
Smelter claim: radioactivity: 286.
Secondary Uranium Minerals—
Forty-Niner, King Solomon Ridge, and West End claims W of Clancey: 253.
Thorium Occurrences—
Boulder Mining District
Free Enterprise claim, Elkhorn Mining Co., near Boulder: pitchblende: 304, 376, 377.
Lake Delmoe: allanite: 210, 236; in gold placers; spectrographic analysis shows no uranium or thorium: 235.
Torbernite Occurrences—
Boulder Mining District
Free Enterprise group, Elkhorn Mining Co., near Boulder: with carnotite: 378.
Uraninite Occurrences—
Boulder: first car-load shipped from state: 388.
Uranium Occurrences—
Alhambra District: prospecting: 388.
Anchor Mining & Milling Co. property, 29 mi. SE of Helena: uranium: 375.
Basin-Boulder-Clancey area
General: 286.
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Clatsop Beach: 217, 317; in black sands: 82; .4 lb. per ton: 11.
Clatsop Spit: 317; in black sands: 82; Columbia River: .1 to .6 lb. per ton: 11.
Elk Creek: .4 to 4 lbs. per ton: 11.
Elk Park: in black sands: 82.
Fort Stevens: 317; in black sands: 82; .2 to 1 lb. per ton: 11.
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Hammond: 317; in black sands: 82; .4 to 2 lbs. per ton: 11.
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Astoria: monazite, from a trace to 131 lbs. per ton: 11; monazite in beach sands: 317; monazite in black sands: 78, 82.
Beach sands: monazite: 281.
Carnahan station: monazite, from a trace to .5 lb. per ton: 11; monazite in beach sand: 317; monazite in black sands: 82.
Clatsop: monazite, 2 lbs. per ton: 11; monazite in black sands: 82.
Clatsop Beach: monazite: 217; monazite, .4 lb. per ton: 11; monazite in beach sand: 317; monazite in black sands: 82.
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Elk Creek: monazite, .4 to 4 lbs. per ton: 11.
Elk Park: monazite in black sands: 82.
Fort Stevens: monazite, .2 to 1 lb. per ton: 11; monazite in beach sand: 317; monazite in black sands: 82.
Gearhart Beach: monazite, .1 lb. per ton: 11; monazite in beach sand: 317; monazite in black sands: 82.
Gearhart Park: monazite, .4 to 1 lb. per ton: 11; monazite in black sands: 82.
Hammond: monazite, .4 to 2 lbs. per ton: 11; monazite in beach sand: 317; monazite in black sands: 82.
Morrison: monazite, .3 lb. per ton: 11; monazite in black sands: 82.
Seaside: monazite, 1 lb. per ton: 11; monazite in black sands: 82.
Warrenton: monazite, .1 to 1 lb. per ton: 11; monazite in beach sand: 317; monazite in black sands: 78, 82.

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Randolph Mining District: 78, 82, 217; beach sand from a trace to 1 lb. per ton: 11.
South Fork Coquille River: 82; .4 lb. per ton: 11.

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Randolph Mining District: monazite: 78, 82, 217; beach sand: monazite, from a trace to 1 lb. per ton: 11.
South Fork Coquille River: monazite: 82; monazite, .4 lb. per ton: 11.

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Gold Beach: 78, 82, 217; .5 lb. per ton: 11.
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Eckley: monazite: 82.
Gold Beach: monazite: 78, 82, 217; monazite, .5 lb. per ton: 11.
Port Orford: monazite: 82, 217; monazite, .1 lb. per ton: 11.

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Denio: uranium coating: 317.
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Hood River: monazite: 78, 82; beach and sand bar, monazite, .4 to 5 lbs. per ton: 11.
Hood River, Columbia River: monazite, .5 to 1 lb. per ton: 11.
Hood River Beach: monazite: 217.

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Sucker Creek: 78, 82; 12 lbs. per ton: 11.
Wolf Creek: 82, 217; .1 lb. per ton: 11.
Thorium Occurrences—
Holland: monazite: 78, 82; monazite, 24 lbs. per ton: 11.
Kerby Mining District: monazite, trace: 11.
Placer: monazite: 78, 82; monazite, 46 lbs. per ton: 11.
Sucker Creek: monazite: 78, 82; monazite, 12 lbs. per ton: 11.
Wolf Creek: monazite: 82, 217; monazite, .1 lb. per ton: 11.

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Yaquina Bay: trace: 11.
Thorium Occurrences—
Yaquina Bay: monazite, trace: 11.

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Foster: 78, 82, 217; .1 lb. per ton: 11.
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Foster: monazite: 78, 82, 217; monazite, .1 lb. per ton: 11.

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Fulton: 82; .5 lb. per ton: 11.
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Latourell: monazite: 78.
Latourell, Columbia River sand: monazite, 479 lbs. per ton: 11.
Latourell Falls: monazite: 82.
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Weston: monazite: 78, 82, 217; monazite, 46 lbs. per ton: 11.

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Antone: monazite: 78, 82; monazite, 2 lbs. per ton: 11.

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Marcus: monazite, trace: 11.
Wilmot Bar, Columbia River: monazite: 78, 82; monazite, 30 lbs. per ton: 11.

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Monazite Occurrences—
Bald Mountain Mining District: 78, 82; 2 lbs. per ton: 11.
Thorium Occurrences—
Bald Mountain Mining District: monazite: 78, 82; monazite, 2 lbs. per ton: 11.

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Deposit on Great Pine Ridge 16 mi. SW of Pumpkin Buttes: coal bed with highest scintillometer reading contained 0.003% uranium and 0.001% equivalent uranium: 261; sample from siltstone of clinker zone contained 0.062% uranium and 0.10% equivalent uranium: 261; sample of tan siltstone 35 ft. NE of the face contained 0.1% uranium and 0.12% equivalent uranium: 261; uranium at top of Fort Union fm. adjacent to a clinker and baked siltstone zone: 261.
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Black Sulfur Spring near Big Spring, Thermopolis: radium emanation, trace: 293.
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Big Spring, Thermopolis: travertine on twigs, radium emanation, 14×10^{-11} g. Ra per gram; travertine, 100 ft. above spring, radium emanation, 1.7×10^{-11} g. Ra per gram; travertine, 600 ft. above spring, radium emanation, 3.5×10^{-11} g. Ra per gram: 293.
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Tom Bush claims on Nigger Hill, a continuation of the Casper Mts.: two radium springs on land; water to be sold commercially: 342; uranium ore estimated to average up to 5–10 lbs. uranium per ton; assayer's report showed 1 lb. per ton: 342.

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Lusk: deposits of gold with radium indication found, assaying $23 per ton: 341; radium extracted from ore: 273; uranium: 219; uranophane: 273; uranophane in dump of old silver mine: 118; uranophane ore shipped in several carloads had uranium content as high as 4% U_3O_8: 273; uranophane production: 384.
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Niobrara County—
Silver Cliff Hill N of Lusk: with uranophane: 335.

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Rathgeb mine near San Andreas: pitchblende and gold in quartz veins: 206; uraconite, uraninite: 275; uraconite, uraninite, with gold: 279; uraninite: 82.
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Merced River: thorite in placers: 228.
Mokelumne River: thorite in placers: 228.
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General: autunite, deposits not worked: 292.
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Darwin: unidentified uranium mineral: 218.
Oasis area: torbernite: 275.
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Natural Resources Developing Co., Bishop, 40 mi. from: uranium: 383.
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Josie Bishop (14) claims in Red Rock Canyon near Cantil: radium mine: 347; unnamed radium-bearing ore: 345.
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Olgaradium claim near Randsburg in Summit Diggings area: secondary uranium minerals: 354.
Radium Group of Josie Bishop claims, Red Rock Canyon near Cantil: unnamed radium-bearing ore valued at $5200 per ton: 346.
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Searles Lake road, 8 mi. NNE of Randsburg: autunite, torbernite: 275.
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Costa Mesa: uranium: 360.
Riverside County—
Box Spring Mountain: fergusonite: 275.
Marshall Canyon near Beaumont: uranium: 359.
Southern Pacific Silica quarry, ½ mi. SE of Nuevo: cyrtolite, monazite, samarskite (?), xenotime, yttrocrasite in pegmatite: 275; monazite, samarskite, xenotime: 226, 227; pegmatites with cyrtolite, monazite, samarskite, xenotime, yttrocrasite (?): 206; samarskite (previously identified as nuevite): 274.

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Atolia Mining Co. mill near Shadow Mountain: autunite: 314.
Mountain Pass, Route 91: bastnasite: 77, 212, 370, 380.
Northeast part: autunite: 279; autunite with torbernite: 275.
Radio Mines Co. of San Bernardino, 90 claims in Ord Mts.: reported uranium ore with gold, silver, and tungsten: 334; to develop and operate deposits: 334; uranium process treatment developed by company: 334.
San Diego County—
General: microlite, pyrochlore: 289; pegmatite with microlite: 264.
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Poncia placer tract in Swede Gulch near center of S.9, T.7N., R.5E., 1½ mi. SE of Pioneerville: polycrase with monazite in heavy sands: 298.
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Avon, 3–6 mi. N. of, mica pegmatites: autunite (?): 190; geographic features: 190; geology: 190; mineralogy: 190; wall rock alteration: 190.
Last Chance mine, Avon mica district, 3 mi. N of Avon and 23 mi. NE of Moscow: autunite, meta-torbernite in pegmatite: 301; geology: 301.
Lemhi County—
Garm-Lemoureaux mine, owned by the estate of Ira Lemoureaux, on Allan Creek, 30 mi. by road N of Salmon: geology: 311; material on dumps contained 0.015–0.13% equivalent uranium and 0.005–0.11% uranium: 311; radioactivity: 311.
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Coeur d'Alene mine: pitchblende: 102; present uranium exposures marginal in grade: 306; small uranium showing: 306; uraninite: 288, 305.
Sunshine mine, Sunshine Mining Co., at Kellogg: carnotite in Pre-Cambrian Belt series: 53; geology: 251; mineralization: 251; most important known potential

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Fluorite, Uranium-bearing: 95.
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Phosphates, Uranium-bearing: 53; low grade uranium ores: 306.
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Many Values prospect 4 mi. from Fox Park: pegmatite with fergusonite (?): 234.
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North-middle Pumpkin Butte, 500 ft. below the top: one sample contained 0.006% uranium and 0.013% equivalent uranium: 261; uranium in soft gray roll in sandstone in Wasatch fm.: 261.
North Pumpkin Butte, S side of: average of six grab samples taken from roll contained 15.14% uranium: 261; uranium deposited as a roll in sandstone and surrounded by black and yellow highly radioactive minerals: 261; uranium discovered in October, 1951, in Wasatch fm. of early Eocene age: 261.
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Tom Bush claims on Nigger Hill, a continuation of the Casper Mts.: two radium springs on land; water to be sold commercially: 342; uranium ore estimated to average up to 5–10 lbs. uranium per ton; assayer's report showed 1 lb. per ton: 342.
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Lorimer Minerals Co. radium deposits at Lusk: concentration mill installed: 225; geology: 225; uranophane ore with 4–50% U_3O_8 content: 225.
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Silver Cliff mine at Lusk: about 100 tons of uranium ore produced by March, 1919: 258; Lambert Ore Co. & Lorimer Minerals Corp. shipped 5 carloads of radium ore between Dec. 1918 & Sept. 1919: 221; shipped ore valued at $33,857.48: 220; legal difficulties caused suspension of mining operations for 5 years and, by the time the title was cleared, world radium was being supplied by Belgian Congo deposits: 220; several carloads of uranium ore with 3% U_3O_8 shipped: 258; some ore specimens carried up to 20% U_3O_8: 258; uranophane: 53, 221; uranophane on quartzite gangue: 220; uranophane, probably oxidized from uraninite, in quartzite, discovered in spring of 1918: 258; valuable ore on dumps: 221.
Silver Hill at Lusk: gummite, pitchblende, uranophane: 254.
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Sweetwater County—
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Lost Creek deposit near Wamsutter: schroeckingerite: 53.
Lost Creek 45 mi. N. of Wamsutter: schroeckingerite: 219.
Minnie McCormick discovery in Red Desert, 35 mi. N of Wamsutter: uranium: 362.
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Radio Mines Co. of San Bernardino: new uranium process treatment developed by company: 334.
Wyoming
Niobrara County—
Lorimer Minerals Co. radium deposits at Lusk: concentration mill installed: 225.
Lusk ores: to be processed at Vitro Chemical Co. plant in Salt Lake City: 384.

Silver Cliff Hill N of Lusk: 50-ton wet gravity uranium concentration plant built by Lorimer Minerals Co. to treat ore: 335.

URANIUM PRODUCTION

Montana
Jefferson County—
Boulder: uraninite, first car-load shipped from state: 388.
Clancey Mining District
Haynes properties 1 mi. W of Alhambra: first uranium shipped from area: 390.

Wyoming
Niobrara County—
Lusk: uranophane: 384.
Silver Cliff Hill N of Lusk: several carloads of ore with 3% U_3O_8 shipped: 335; 50-ton wet gravity concentration plant built by Lorimer Minerals Co.: 335.
Silver Cliff mine at Lusk: about 100 tons of uranium ore produced by March, 1919: 258; Lambert Ore Co. and Lorimer Minerals Corp. shipped 5 carloads of radium ore between Dec. 1918 and Sept. 1919: 221; shipped ore valued at $33,857.48: 220; legal difficulties caused suspension of mining operations for 5 yrs. 221; several carloads of uranium ore with 3% U_3O_8 shipped: 258.

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Wyoming
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Silver Cliff Hill N of Lusk: with some uraninite: 335.
Silver Cliff mine at Lusk: 53, 220, 221; ore shipped contained 3% U_3O_8; some specimens carried 20% U_3O_8: 258.
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URANOPHANE PRODUCTION

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Niobrara County—
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Southern Pacific Silica quarry, ½ mi. SE of Nuevo: with cyrtolite, monazite in pegmatite: 275; with monazite in pegmatite: 264, 279, 297; with monazite, samarskite: 226, 227; in pegmatites with cyrtolite, monazite, samarskite, yttrocrasite (?): 206.
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Southern Pacific Silica Quarry, ½ mi. SE of Nuevo: 275; questionable occurrence in pegmatites with cyrtolite, monazite, samarskite, xenotime: 206.

U. S. Atomic Energy Commission, Box 30, Ansonia Station, New York 23, N. Y.

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CONFIGURATION OF THE ALEUTIAN RIDGE RAT ISLANDS—SEMISOPOCHNOI I TO WEST OF BULDIR I

BY WILLIAM GIBSON AND HAVEN NICHOLS

ABSTRACT

The configuration of a 150 by 200 mile section of the Aleutian Ridge, extending from the Aleutian Trench on the south to the floor of the Bering Sea on the north, is presented by means of depth curves at 50-fathom depth intervals.

Advances in electronic position indicating had enabled the U. S. Coast and Geodetic Survey to complete accurate and detailed hydrographic surveys of this entire area based on accurate horizontal control. The authors used copies of the large-scale survey sheets for adding 50-fathom depth curves. Compilation on Plate 1 accentuated the submarine topography and gave substance to many interesting configurations that were not evident on the published navigational chart. The scale of Plate 1 is designed for regional coverage. Geologists and others interested in more precise and detailed physiography may refer to the large-scale basic survey sheets of the U. S. Coast and Geodetic Survey.

Submarine contours of the Aleutian Trench, a submerged central-cone depression, four sea valleys, and many transverse canyons are shown. Murray Sea valley is completely contained in the study. The Aleutian Ridge is shown to rise in inclined steps from the floors of the Trench and Bering Sea. The Aleutian Bench is a prominent step on the south slope of the Ridge. The volcanic arc is at the north edge of another prominent step on the north slope of the Ridge. Bowie Canyon is a definite submerged line of demarkation between the Aleutian Ridge and Bowers Ridge.

Many implications relative to the formation of mountains, island arcs, and trenches may be seen in the configurations. Vertical and horizontal movement may take place along inclined step faults. The step faults and canyonlike transverse faults may outline irregular crustal blocks where differential movement would occur. Great distortion of the bottom occurs along the edges of the sea valleys. Most of the earthquake epicenters may be aligned along inferred step faults by allowing for probable uncertainties in their locations. Definite correlation between earthquakes and submarine topography, if possible, must wait for more accurate epicenter determinations along the Aleutian Ridge.

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Introduction

The Aleutian Islands of Alaska and the great submerged structure of which the islands are the peaks have now been surveyed in considerable detail with an accuracy and completeness not considered possible even 2 decades ago.

This striking archipelago between the Bering Sea and Pacific Ocean extends more than 1000 miles westward toward Cape Kamchatka, from the western extremity of the Alaska Peninsula, and lies across one of the world's most important sea and air routes. Ships sailing the great-circle route between Puget Sound and Japan pass between the islands at Unimak Pass, north of the island chain, across the Bering Sea, and west of Attu. The northwest air route between North America and Asia used by the United Nations airplanes engaged in commercial and military airlift to Japan and Korea uses bases and air-navigation facilities on these islands.

The recent events of history have given added impetus to the long-range program of the United States Coast and Geodetic Survey for reconnaissance of this strategic island chain. These basic surveys made for our national needs in defense, trade, and commerce now reveal the physiographic character of one of the most interesting submerged geologic structures in the world. The Aleutian arc contains a long recorded history of intense volcanic and seismic activity, stands along the rim of the northern slope of the Aleutian Trench, and has been the subject of much study and speculation by seismologists, volcanologists, geologists, oceanographers, and students of the earth's history for many years.

Acknowledgments

In offering this note to science the authors wish to pay special tribute to their many shipmates and colleagues in the U. S. Coast and Geodetic Survey whose individual efforts in the routine line of duty have made such a paper possible. The extension of geodetic, topographic, and hydrographic surveys over the Aleutian Islands has demanded extraordinary ingenuity, ability, and perseverance. The region is notorious for storms, treacherous seas, and thick weather. The coasts are rugged, and boat landings are hazardous. In the earlier years of the surveys and even yet these islands are remote from sources of supplies and emergency services. A few of the officers and men of the survey parties have lost their lives in the field work. Many engineers, cartographers, draftsmen, and lithographers have contributed to the computations, reviewing, verifying, and assembling of the mass of engineering data upon which Plate 1 is based. To all of these contributors we make grateful acknowledgment. The authors shared the inception of this study and about half of the compilation of Plate 1. The senior author completed the plate and prepared the text and illustrations after Lieutenant Colonel Nichols was called to active duty with the U. S. Air Force.

For encouragement and helpful suggestions when reviewing this paper, the authors are indebted to Rear Admiral Paul A. Smith, Dr. Francis P. Shepard, Dr. Perry Byerly, Dr. Howard A. Powers, and Dr. Robert R. Coats.

General Background

William Bowie (1926, p. 121) said:

> "As far as the Aleutian Islands are concerned, we have scant data . . . there should be detailed soundings . . . around the islands . . . across the axis of the chain . . . across the edge of the shelf . . . across the deeps. With such information we should be able to take further steps in studying the history of the islands from the geological standpoint."

Bucher (1932, p. 16) described island arcs and trenches as welts and furrows formed by stresses in the earth's crust and vertical adjustment, wherein the furrow or trench is formed first by tension followed later by the welt or arc resulting from the over-riding of the edge of the furrow by differential crustal movement caused by compression. He has also pointed out that all the characteristics of island arcs and deeps are found on land along mountain ranges. He looked to the hydrographer for the detailed configuration of critically chosen sections of the ocean floor.

Heck (1932, p. 21) wrote that the relation between earth-quake occurrence and submarine relief can be established only in a general way because accurate facts regarding both the position of earth-quake epicenters and

bottom topography must be known in detail. He listed as requisites for accurate knowledge of epicenters the existence of sensitive seismograph stations reasonably near the epicenter, accuracy of time, and accuracy of travel-time curves for the local surface layers, depth of origin, and thickness of the layers under the ocean. He further lamented the fact that in the known 2000 miles of the Aleutian Trench there were at that time only 15 poorly spaced soundings to prove its existence and none to show its contours.

Paul A. Smith (1941, p. 395) pointed out that the geologic significance of the results of surveys of the submerged continental margins is a not unimportant byproduct, a more extensive knowledge of which will contribute to a better understanding of that part of the earth history hidden beneath the sea.

W. T. Thom, Jr. (1942, p. 708–709) stated that the world's main volcanoes are found either within the major seismic areas or along linear zones where tensional fracturing of the crust has been produced by differential crustal shifts along straight-line fractures. The world's major seismic areas are essentially coincident with the world's great linear zones in which active mountain building is now taking place. Fracturing and buckling of the crust is being caused by differential horizontal movements of the several main coastal segments outlined by these interconnecting fracture systems.

Murray (1945, p. 759) has illustrated the arcuate nature of the islands, peninsulas, and foredeep by a 1450-mile arc of 760-mile radius centered near Mys Navarin on the Siberian coast. He also described the 125-mile arc containing Bowers Ridge, the little-known mountain rising to 12,000 feet above the flat and featureless bottom of the Bering Sea. Coats (1950, p. 43) pointed out that the volcanic line consists of superficial structures along segments of many different arcs. Recently, however, Menard and Dietz (1951, p. 1274–1279) have shown the arcs of the Aleutian Trench and the volcanoes to be concentric from Kiska to Umnak Islands. The distance between the volcanic arc and the trench then increases eastward from Umnak Island to approximately 200 miles near the Kenai Peninsula. They find sufficient agreement between the geological history of Alaska bordering the eastern section of the Aleutian Trench and Umgrove's theory of the formation of pseudo-single island arcs to infer a Mesozoic trench in the area now occupied by Kodiak Island and the Kenai Peninsula.

The United States Geological Survey (1947) provides much detailed information on the volcanoes and geology of the Aleutians. The U. S. Geological Survey is currently surveying and studying the general geology and volcanology of the Aleutians. H. A. Powers (personal communication, 1952) states from his personal observations that the islands of Semisopochnoi, Little Sitkin, Kiska (north of the harbor), and Buldir are made of rocks younger than Middle Tertiary. In contrast, Amchitka, Rat, Little Kiska, and Kiska (south of the harbor), are made up of rocks most of which are older than Middle Tertiary. Fault systems are not well expressed in the younger formations, but, in the older southern islands, many faults with a great range in age can be classified in four major groups on the basis of direction of trend: namely, east, north, northeast, and northwest. Many dikes of volcanic rock and zones of hydrothermal alteration are aligned along the east-trending fault direction. In some places the east-west dikes have been offset by later movement along either northwest- or northeast-trending faults. Coats (1947) made a preliminary report on the geology of the western Aleutians. Some of his findings are briefly summarized.

The geologic history is replete with submergence, emergence, volcanism, faulting, and glaciation. He inferred a north-south trending oldland in Paleozoic time and related late volcanic activity to an east-west fault or fracture zone extending the length of the arc. There is much shearing and faulting in pre-Tertiary formations. Pleistocene faults trending northeasterly cut the glacial till of Amchitka. North-south and east-west structural trends are expressed in part by parallel and transverse faults. Vents of late volcanic activity lying generally north of the older ones are related to the east-west fault zone. Caldera-forming eurptions have occurred and may occur again. Some areas of Tertiary volcanic rocks have been leveled by marine erosion. Several fluctuations

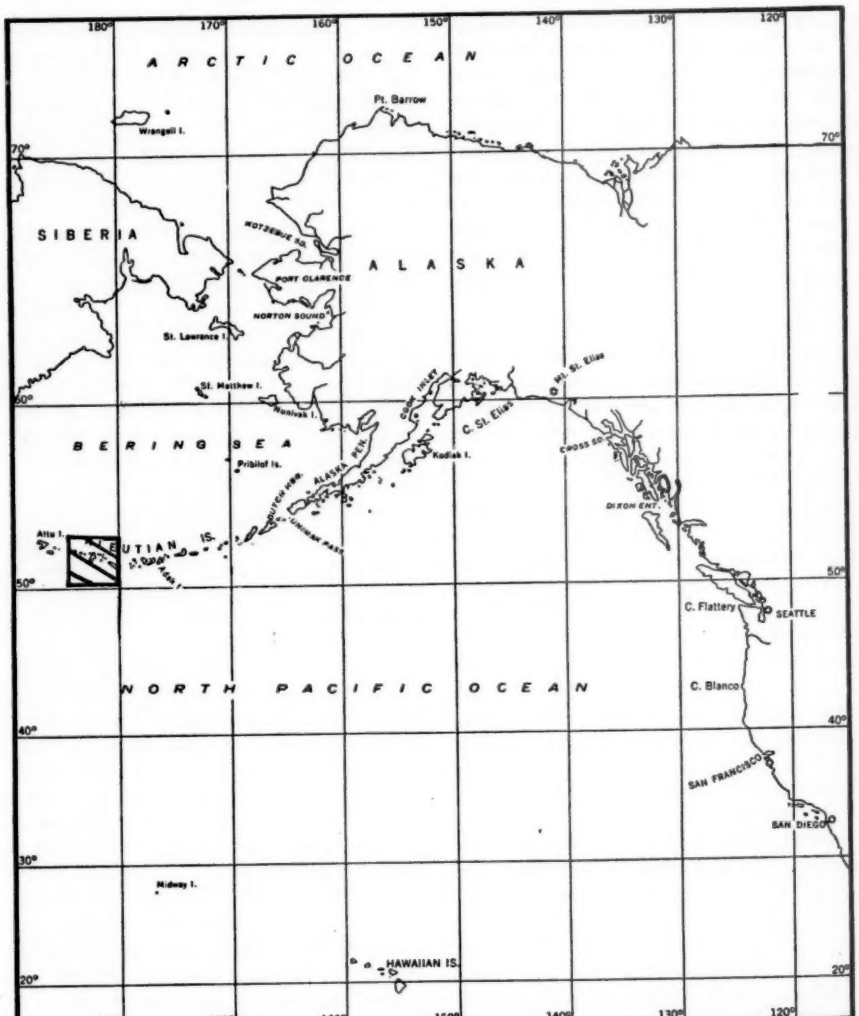

FIGURE 1.—INDEX MAP, SHOWING LOCATION OF PLATE 1

of the relative sea level are indicated in late Tertiary time. Coats (1947, p. 103–104) further commented:

"It is inevitable that many gaps and uncertainties should be present in any discussion of the structure of the western Aleutian Islands, because of lack of information about many of the islands, concealment of many critical exposures beneath the sea. . . ."

Many of the leading scientists have been looking to the hydrographer for a detailed configuration of the ocean floor. Survey data valuable in the study of mountain building are now available in the Coast and Geodetic Survey hydrographic files for extensive coverage of the Aleutian Ridge in much greater detail than can be shown on Plate 1. This study is one of several nautical chart sections of the Aleutian Ridge. The surveys of the ocean bottom along this section of the Ridge and Trench are very comprehensive and have far surpassed Bowie's

and Heck's expectations. Advances in seismology fulfill most of Heck's requisites for correlation between earthquake occurrence and submarine relief, but accurate epicenter determination there has lagged for lack of a sufficient number of modern seismograph stations.

Survey Methods and Accuracy

Shoran and Electronic Position Indicating

One modern trend in navigation has been the fixing of position during times of poor visibility on the approach toward dangerous waters by comparison of measured depths with the bottom configuration shown on charts based on accurate and complete surveys. This trend was largely responsible for the comprehensiveness of the surveys of the Aleutian Ridge. The method has its greatest utility here where there are few radio aids to navigation and many prominent relief features on the bottom of the sea. The fulfillment of the navigational requirements also met the scientific needs for accurate bottom configuration indicated by Heck, Bowie, and others.

Complete and comprehensive surveys were accelerated through the adaptation of shoran and electronic position indicating to position fixing at sea by the U. S. Coast and Geodetic Survey (Burmister, 1948). Shoran is a very accurate and dependable method for measurement of distances up to about one half greater than the line of sight between the ship and the shore stations. Distances up to 100 miles have been obtained, but at considerable additional expense because of waiting for the upper atmospheric condition necessary for reflection of the radio waves which are unpredictable. Surveys along the foot of the insular slopes were made with shoran under these conditions prior to the adaptation of electronic position indicating (EPI). Electronic position-indicating equipment had been developed by the U. S. Coast and Geodetic Survey on account of the line-of-sight limitation of shoran. It provides the range and accuracy to survey entirely the Aluetian Ridge and Trench as well as great ocean areas. The Explorer work of 1952 in surveying the Aleutian Trench is believed to be the first accurate and controlled survey of such a submarine feature. However, the only use of EPI in the area of this study was along the junction of the Aleutian Trench and Murray Sea valley.

The full capabilities of shoran and electronic position indication, EPI, have not been utilized for economic reasons. Since the accuracy is independent of the distance from the shore stations, critically chosen sections of the ocean floor may be surveyed on large scales to obtain more exact definition. For instance, the extent and shape of many of the seamounts or sections of the Aleutian Trench within range of EPI could be developed by well-controlled, closely spaced sounding lines on a large-scale sheet.

Geodetic Control and Soundings

Geodetic control has been extended from the mainland of Alaska over the entire length of the Aleutian chain. All positions and soundings are adjusted to the North American datum of 1927.

The depths used in this study are from echo soundings which have been corrected for all factors except slope. Approximately 100,000 plotted soundings form the basis for the submarine contours. In evaluating the submarine topography it is manifestly impossible to count the number of soundings on a fathogram; and no particular gain would accrue from counting the number of processed and usable soundings. Many more soundings were taken than could be plotted on the survey sheets, which in turn were reduced 3 to 20 times for compilation on Plate 1. The loss of detail in reducing the scale of the survey sheets to that of the compilation was minimized by carefully drawing all the desired depth curves on the survey sheets prior to reduction and transfer. Only the depth curves and critical soundings were transferred.

In accordince with standard nautical chart-construction practice, depth curves at wide intervals had been added to each survey sheet by the hydrographers in the field, checked in the processing offices, and reviewed by the cartographers and engineers of the Washington Office of the U. S. Coast and Geodetic Survey. Addition by the authors of the numerous 50-fathom interval depth curves greatly emphasized the configuration. The older official curves were revised occasionally when the

additional data made the necessity evident. However, the accuracy of the determination of these bottom configurations is more dependent on the number, spacing, and direction of the sounding lines than on the number of soundings. The engineers who made the surveys in the field were guided by the need for sufficient data to delineate adequately the depth curves. A failure to conform to this specification occurred along the bottom of the north insular slope extending west from the longitude of Segula Island. Sounding lines spaced at 3- and 4-mile intervals were obtained there with shoran under great difficulty. Even so, the bottom topography would have been adequately delineated there with 3- and 4-mile sounding lines if their orientation had been other than north and south. Some significant data may have been missed in contouring there because the north-south sounding lines parallel the canyons.

Orientation and Accuracy of Configuration

The orientation of the lines south of Amchitka was excellent for indicating the warping of the bottom, but closer spacing of the lines would have made this important inference more nearly positive. Elsewhere the development was excellent. The Buldir formation was covered by sounding lines spaced about half a mile apart. The south insular slope was covered with lines varying from less than half a mile apart near the island ridge to 4 miles apart below the foot of the insular slope. Lines spaced at 8-mile intervals across the Aleutian Trench, because of their north orientation, crossed the depth curves at the most favorable angle for contouring. Closer spacing of sounding lines would add little to the accuracy of the general configuration of the trench area. The ravines, ridges, and knolls unquestionably exist; the details of their shapes could be improved. More accurately detailed configuration of the trench could be obtained only by a large-scale EPI survey.

Place Names

The new data derived from contouring the original large-scale surveys were applied to Coast and Geodetic Survey standard chart bases of the area. The area of Plate 1 is covered for the most part by U. S. Coast and Geodetic Survey Chart 8864 and the eastern portion of Chart 8865 (Fig. 1). Plate 1 is the first of a series of six charts to be revised from the new surveys. There are very few authentic place names for the submarine features, and the authors have supplied many names to facilitate description.

Prominent Features

General Statement

The main features of this study (Pl. 1) are sections of the Aleutian Trench, Aleutian Bench (so-called by Murray), Aleutian Ridge, and Bowers Ridge. In many cases detailed configuration of each feature is available. The Aleutian Ridge is made up of the insular slopes, the crest, and volcanic arc. The insular slopes, the bench, and trench walls are indented by many submarine valleys, canyons, and troughs. The physiography of the insular borderland between the crest and the trench is suggestive of a series of step faults as described on the continental slopes by Shepard (1948, p. 193). The exaggerations of the vertical scale of the profiles (Figs. 3, 4) emphasize the steps which have slopes of 5°–6°. The clarity of the undersea forms may be due to the absence of heavy sedimentation which usually masks the continental margins.

Aleutian Trench and Bench

The configuration of the north and south slopes of the Trench are remarkably different and may have real significance in the study of the mechanism of trench formation (Fig. 2). Profiles of the trench, bench, and ridge conform generally with those depicted by Murray (1945, p. 765–773) to the eastward.

The bottom of the trench is roughly outlined by the 3950-fathom curves which mark the transition from the slopes to the remarkably flat bottom. It lies only 34 nautical miles south of the 100-fathom curve of Tahoma Reef. The tendency toward parallelism of these depth curves, which delimit the bottom of the trench, suggests a tensional separation. Kiska Deep is based on a single line of soundings. The

alternating ridges and valleys of the south trench wall suggest compression, buckling, or folding (Fig. 2). The lack of relief in the bottom of the trench is indicative of fault gouge, southern part is characterized by a succession of knolls or swells with attendant depressions or basins at the top of the steep north side of the trench. Thurmond and James basins

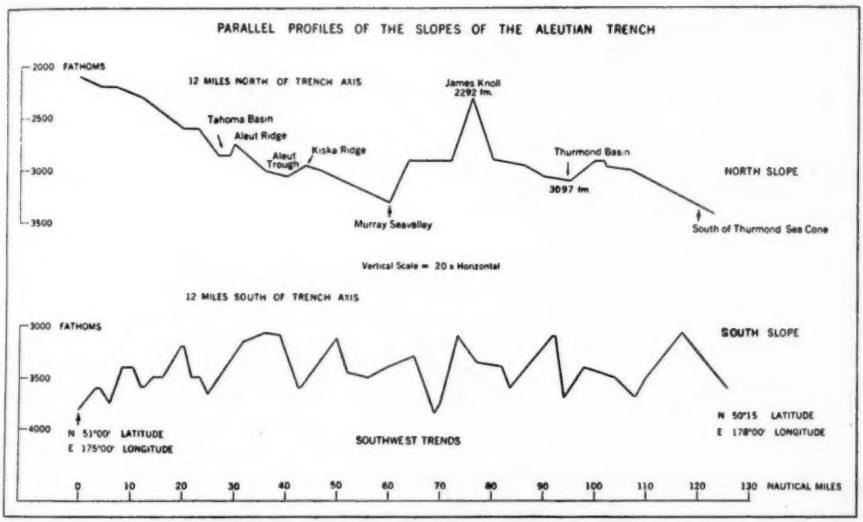

FIGURE 2.—PARALLEL PROFILES OF THE SLOPES OF THE ALEUTIAN TRENCH

similar to that ground up between fault planes on the surface (Fig. 6). The north slope of the trench rises steeply to the Aleutian Bench. This first break in the slope above the trench bottom is not regular but ranges from 2600 fathoms depth on the west to 3100 fathoms across the Aleutian Bench, and 3050 fathoms in Murray Sea valley. The Aleutian Bench comprises the area between this break in the slope and the foot of the south insular slope. The foot of the south insular slope is not always clear but appears to lie at about 2300 fathoms depth southwest of Tahoma Reef, in Murray Sea valley, and Vega Canyon, 2200 fathoms depth at Rat Island Canyon, and 1750 fathoms at the foot of Seymour Canyon. From Seymour Canyon eastward the foot of the insular slope is not well defined except at the west edge of Amchitka Sea valley where Ward Canyon ends in the elongated basin.

The Aleutian Bench is very irregular in relief, and might be a recent structural feature. The appearance of the northern part of the bench suggests tension during formation. The are among the largest of these. The lower part of Murray Sea valley prolonged northward from where it rises steeply from the trench east of Kiska Basin would merge with that of Vega Canyon on the insular slope except for the Aleutian Bench which intervenes.

South Insular Slope

The rise of the ocean floor from the Aleutian Trench to the top of Kiska Volcano is 28,705 feet in 78 nautical miles or an average of 366 feet per mile. The rise to Sea Lion Pass is 293 feet per mile (Fig. 4). The slope of the bottom of Murray Sea valley which cuts back into the insular slope is 363 feet per nautical mile. The steepest part of this slope is 680 feet per nautical mile charted south of Tahoma Reef between the Trench and the Shelf.

The insular slope between the Shelf and the Aleutian Bench is noteworthy for its canyons, seavalleys, knolls, domes, and depressions. The succession of canyons suggests interconnecting fissures, folds, or thrusts, between adjacent

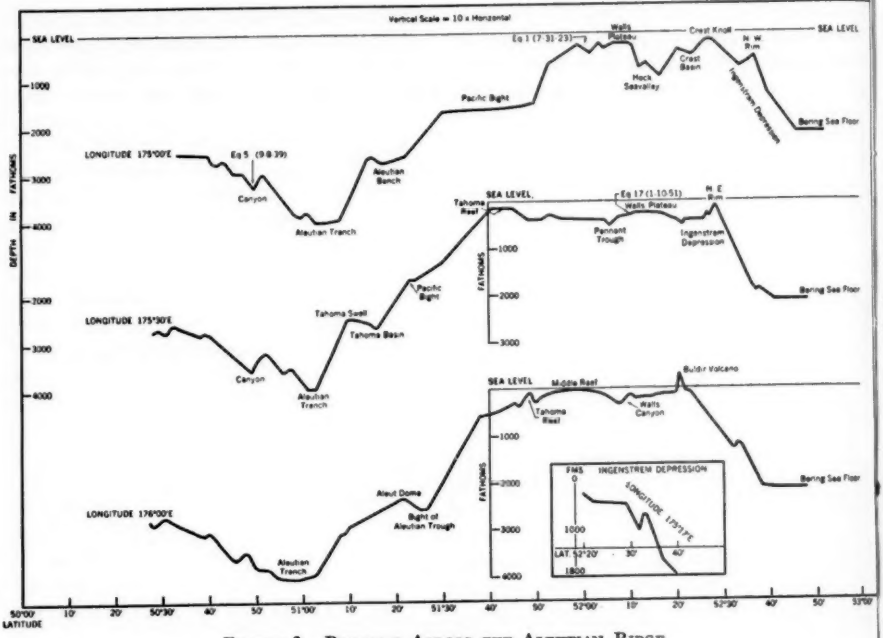

FIGURE 3.—PROFILES ACROSS THE ALEUTIAN RIDGE

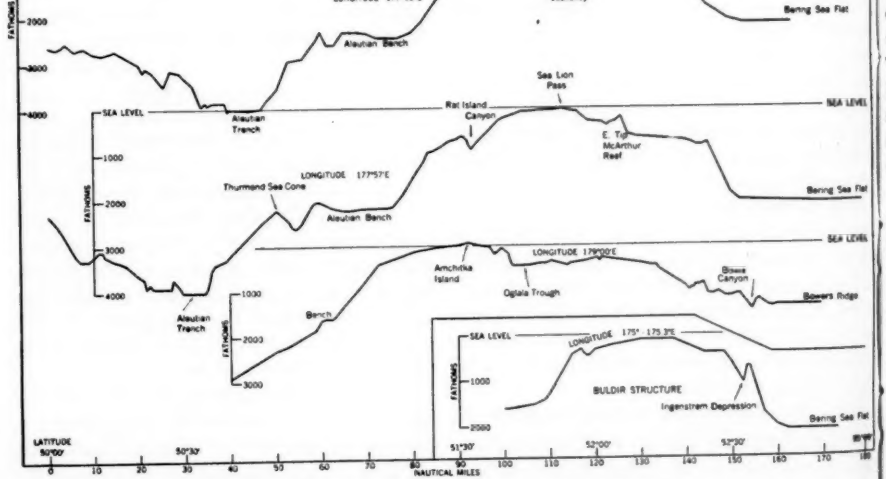

FIGURE 4.—PROFILES ACROSS THE ALEUTIAN RIDGE

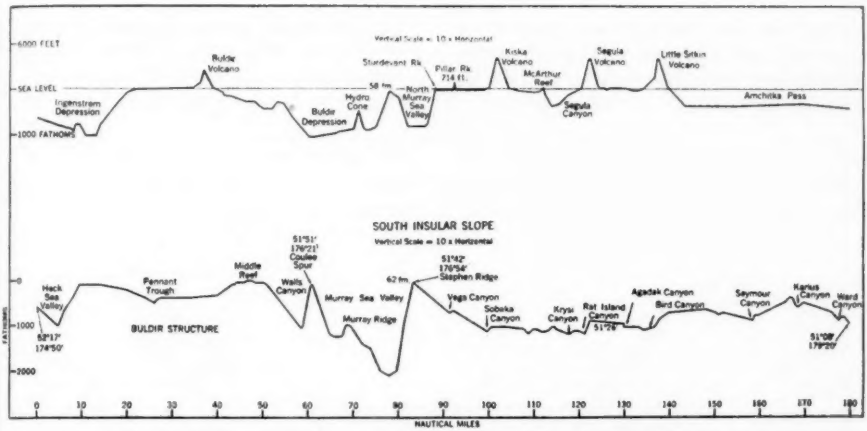

FIGURE 5.—PROFILES ALONG THE ALEUTIAN RIDGE, ARC OF VOLCANOES

crustal blocks as described by W. T. Thom, Jr. (1942, p. 709). Differential crustal movements along such fracture zones might be expected. The canyons descend from the insular shelf to depths of 1800 and 2200 fathoms at the Aleutian Bench where they end or become masked by liment. Some indications of their traversing of the shelf strengthen the belief that they are transverse faults. Unlike drainage features these canyons are deeply submerged and do not occupy low positions in the terrain (Figs. 5, 6). Many of the canyons have curving trends which may be attributed to crustal deformation. This is especially notable in the vicinities of Murray and Amchitka sea valleys. The cross sections of Rat Island Canyon (Fig. 7) show a very steep east wall where the submarine contours bend sharply to the north for a maximum distance of 8 miles. The slope of the axis of the canyon is 420 feet per mile.

Murray Sea valley is the most prominent such feature of the entire area and one of the largest yet known. It bends sharply to the southeast at Murray Basin and traverses the Aleutian Bench to the Trench. Its total length is about 80 nautical miles. The slope of the east valley wall at the 62-fathom spot on Stephen Ridge is 2840 feet per nautical mile for a distance of 4.2 miles. The valley above the 2000-fathom curve rises 1900 fathoms in 20.8 miles or 570 feet per mile. The width is 10 miles at the head and 20 miles between Stephen Ridge and Coulee Spur. The maximum depth

FIGURE 6.—TRANSVERSE FAULT ACROSS AN ISLAND OF THE ALEUTIANS

below the rim is 11,628 feet; the width rim to rim, 17 miles; average gradient, 279 feet per mile; length used for gradient, 80 nautical miles; maximum gradient, 840 feet per mile for 5 miles and 470 feet per mile for 24 miles.

Amchitka Sea valley is not complete in this study, but it appears to be much smaller than Murray Sea valley, and the walls are not so steep. Its head, at the narrowest part of shelf break would appear. A casual examination of these basic data indicates that the break occurs between 70 and 80 fathoms depth. The shelf break is roughly defined by the 100-

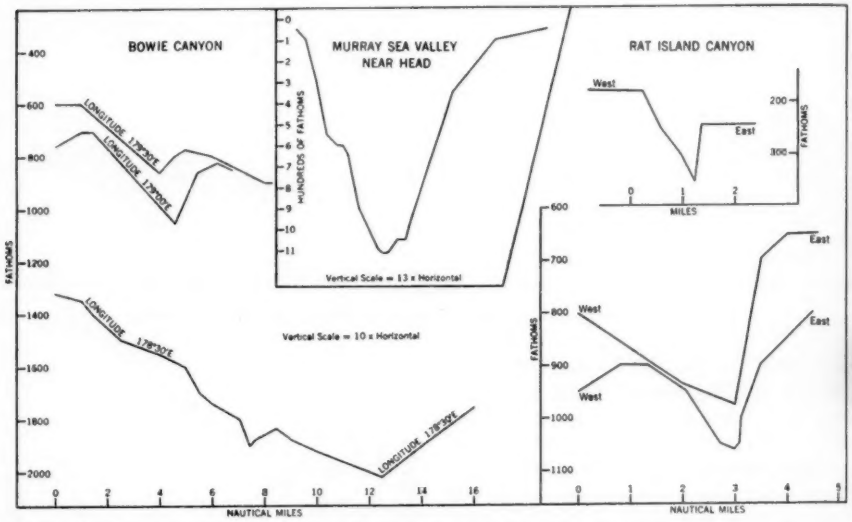

FIGURE 7.—CROSS SECTIONS OF BOWIE CANYON, MURRAY SEA VALLEY, AND RAT ISLAND CANYON

the submerged crest, is barely separated from Sunday Basin. Constantine Arm parallels the north shore of Amchitka Island for 11 miles and ends high up on the slope of Amchitka Sea valley at the 650-fathom level.

The insular slope southward from Buldir, between Murray and Heck sea valleys, contains an area of about 1600 square miles in which various troughs, knolls, and domelike structures are found at comparatively shallow depths. The distance between the insular shelf and the trench is the minimum here, and the interposition of the 1600 square-mile shoal or uplifted area greatly steepened the slope southward to the bench. Pacific Bight suggests sloughing off or downfaulting along an inclined plane.

Insular Shelf

The insular shelf is defined generally by the 100-fathom curve. However, if intermediate curves were drawn between the 50- and 100-fathom lines a more concise picture of the fathom curves east of Semisopochnoi Island and Petrel Bank but is very poorly defined to the westward.

Little is known of the character of the bottom materials in the submerged island passes. The shelf bottom around Kiska, Rat, and Amchitka islands, and Buldir Reef, is irregular and lumpy. Current scour might account for Pillar Reef and Basin in the bight west of Kiska. Present drainage streams from the islands probably have very little effect on the shelf.

Crest of the Aleutian Ridge

This feature outlined by the 50-fathom curve is quite evident on Plate 1 except in Amchitka Pass and west of Buldir. It does not include Semisopochnoi which is considered a feature of the slope. The crest is submerged across Amchitka Pass where it extends between Chitka Point and Ulak, barely separating Sunday Basin and Amchitka Sea valley. The

crest between Buldir Island and Crest Knoll is obscure.

North Insular Slope

The 2100-fathom curve representing the junction of the insular slope and the Bering Sea is within 15 miles of the Aleutian Crest at longitude 175°00′ east. The slope from the north rim of Ingenstrem Depression to the 1000-fathom curve is 17 per cent. Eastward from this point the northern slope widens gradually to a point north of Rat Island where it merges with the west slope of Bowers Ridge. The submarine canyons on this slope differ somewhat from those on the south slope of the ridge. Some start well below sea level but do not continue to the bottom of the slope, and are more meandering in their courses. However, this is not quite clear because the lines of soundings ran generally north and south and were widely spaced in the deep water. Indications of the continuation of the canyons to the Bering Sea flat would not necessarily have been obtained without a closer spacing or a different orientation of the sounding profiles. Sitkin Canyon traverses the entire slope to the bottom of the Bering Sea. It does not have tributaries of any consequence like a drainage stream. Sitkin Canyon descends 2000 fathoms in 45 miles. Its average gradient is 267 feet per nautical mile, but at the lower end it descends 950 fathoms in 8 miles or 713 feet per nautical mile. From the 1100-fathom curve to the head of the canyon between Davidof and Little Sitkin islands the slope is about 170 feet per nautical mile.

Other canyons trend across the entire slope from the head of Murray Sea valley, the north side of Buldir Depression, and Buldir Volcano. Segula Canyon could extend farther northward than shown.

The slope northwest from Semisopochnoi, is quite irregular. Williams Crater with its small central cone lies about 12 miles northeast of Little Sitkin. Bowie Canyon, more than 80 miles long, is the dominant feature of the northeast region of the sheet. Its tributary system has the appearance of a well-developed drainage system. Noteworthy, however, is the absence of tributaries on its north slope. This canyon constitutes a very narrow and definite line of demarcation between the configurations of the Aleutian Ridge and Bowers Ridge. Bowie Canyon gradient is about 140 feet per nautical mile. Three cross sections of the canyon are shown in Figure 4.

FIGURE 8.—TROUGH IN EAST RIM OF SEMISOPOCHNOI CALDERA

Some geologists believe that Semisopochnoi was once a 10,000-foot volcano that has since collapsed into a central-cone caldera. Its east and west walls have been breached and glaciated. The configuration of the east breach (Fig. 8) is believed to be similar to that of the east rim of Buldir Depression.

The upper heads of Oglala Trough and Segula Canyon are separated by the bank extending southwest from Little Sitkin Island. The lower extremity of Oglala Trough appears to be in Sunday Basin. Just to the north of the north rim of Sunday Basin is the head of Pochnoi Sea valley which trends northeastward across the insular slope (off the eastern limits of Pl. 1).

Volcanic Arc

The Volcanic Arc (Fig. 5) lies north of the crest of the ridge and appears to be a recent structural feature related to the north insular slope rather than the shelf. Ingenstrem Depression and Hydro Cone in Buldir Depression are precisely on the volcanic arc which comprises Buldir (inactive), Kiska (active), Segula (active), Kvostof (inactive), Davidof (inactive), Little Sitkin (active), and Sugar Loaf (active) volcanoes. Sturdevant Rock, Pillar Rock (110 feet), and McArthur Reef also mark the Volcanic Arc. Pillar Rock resembles a volcanic neck. The great caldera on Semisopochnoi lies somewhat north of the line between Little Sitkin and Garoloi. This postglacial central-cone type caldera is surrounded by parasitic cones. Ejecta from these vents must have had much to do with the formation of Petrel Bank and the gentle submarine slopes around Semisopochnoi Island.

Many writers have postulated a fault or fracture zone extending the length of the arc to account for the late volcanic activity. The submarine topography (Pl. 1) tends to support this inference. Sunday Basin, Oglala Trough, Buldir Depression, East Cape Canyon, Ingenstrem Depression, and other similar forms

TABLE 1.—CALDERAS OF THE JAPANESE AND ALEUTIAN ARCS

Authority	Location	Caldera	Dia. km.	Area km.²	Central cone	Depth of floor below rim (ft)
		Japanese Arc				
Williams	Kyushu	Aso	17 x 25	379	Yes	1376
	Kyushu	Aira	24 x 23	429	Yes	1376
	Kyushu	Ibusuki	26 x 12	325	Yes	
	Kyushu	Kikai	22 x 13	230	Yes	1280
	Hokkaido	Kuttyaro	26 x 20	430		
	Hokkaido	Akan	24 x 13	244		
		Aleutian Arc				
Coats	Unimak	Fisher	10 x 11			
	Alaska Peninsula	Aniakchak	9.7 x 8.4			
		Veniaminof	8.4			
		Frosty	5.6			
	Aleutians	Tanaga	11			
		Semisopochnoi	6.1 x 7.5			
		Little Sitkin	4.5			
		Kliuchef (Atka)	4.5			
		Kanaton (Kanaga)	4			
		Davidof	2.4			
U.S.G.S.		Umnak (Okmok)	12.0		Nine	1500–2500
Gibson and Nichols	Rat Islands	Buldir	19 x 33	600	Hydro	2910–6000
	Rat Islands	Ingenstrem	10 x 28		No	3654

tions on the next chart to the westward may be the exposed sections. Volcanism has undoubtedly filled or obscured many portions of this zone which has some of the characteristics of another trench. McArthur Reef and Pillar and Sturdevant rocks may be old vents along this same zone.

The existence of Hydro Cone in Buldir Depression and remnants of a surrounding rim give credence to a collapse-caldera hypothesis. Active multiple vents similar to the Segula-Khostov-Little Sitkin formation could account for much deposition on the northern slope as well as to the south and west. The seaward bulge in the 2100-fathom curves north of Hydro Cone on the axis of Strandberg Canyon may have been formed by the transporting of

volcanic material down the slopes. Howel Williams (1941, p. 277) listed four great calderas of Kyushu, Japan, with central cones

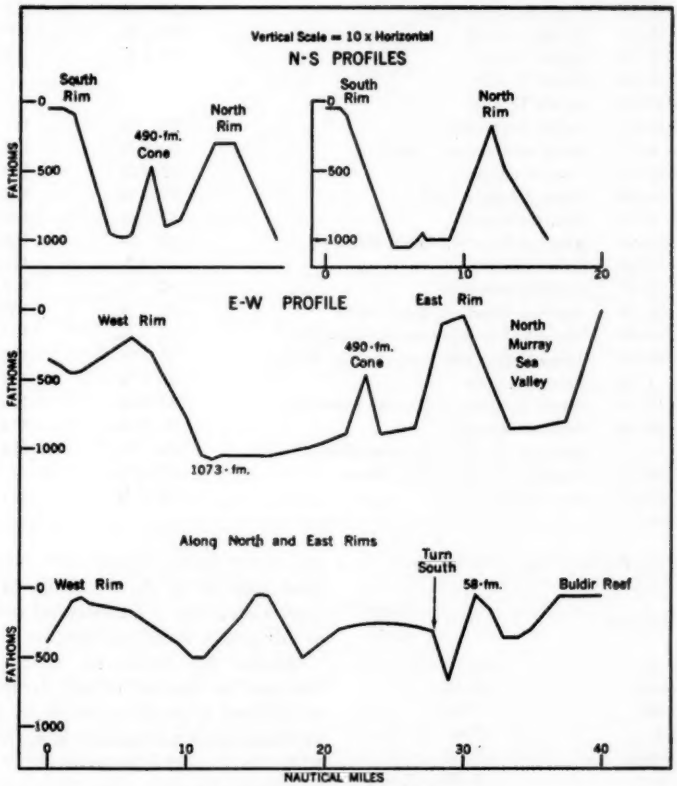

FIGURE 9.—BULDIR DEPRESSION

in Table 1. The depth below the rim was obtained from other sources. These were all produced by engulfment after great pyroclastic eruptions. Coats (1950, p. 43) lists the calderas of the Aleutian Islands, including Semisopochnoi, Davidof, and Little Sitkin. One of the largest in the Aleutians is on Tanaga Island, about 90 miles to the eastward, and measures about 7 miles in diameter. The largest calderas of the Japanese and Aleutian arcs are listed in Table 1 together with two of the largest submerged depressions on Plate 1 of this study. The data on Buldir and Ingenstrem depressions (Figs. 4, 6, 9) are listed for comparison, but not necessarily to show they are collapse calderas. The area and depth below the rim of Buldir Depression (Fig. 9) far exceed any others. Ingenstrem Depression (Figs. 4, 6) is believed to be tectonic on account of the steep northern slope which descends 6000 feet in 3 miles. On the basis of the physiography, differential vertical movement along an inclined fault plane seems to be the best explanation for all the subsidence along the north slope of the Aleutian Ridge west of Buldir Depression.

SEISMOLOGICAL ASPECTS

The submarine topography of the Aleutian Ridge and Trench can be made adequate for correlation with earthquake activity by giving the remainder of the ridge the same treatment as in this study. Steps should be taken now to improve the accuracy of the epicenter locations.

TABLE 2.—LIST OF EARTHQUAKES (1917–1951)

No.	Date	Associated feature	Latitude	Longitude
1	7–31–23	Head of Pacific Bight	52 N.	175 E.
2	11–15–27	Aleutian Bench	51 N.	179 E.
3	2– 2–30	Oglala Trough	51.7 N.	179.3 E.
	4–26–30	Oglala Trough		
	5–20–30	Oglala Trough		
4	8–21–39	Buldir Depression	52 N.	177 E.
5	9– 8–39	South of Aleutian Trench	50.8 N.	174.7 E.
6	3–27–40	Bowie Canyon (?)	42.2 N.	179.5 E.
7	7–14–40	Head of Oglala Trough	51.7 N.	178.5 E.
8	9– 9–45	Aleutian Bench	51 N.	180
9	11–22–48	Aleutian Bench at Ward Basin	51 N.	180
10	12–12–48	Sitkin Canyon	52.2 N.	178.2 E.
11	8–25–49	Pochnoi Seavalley	52 N.	179.9 W.
12	11–28–49	Aleutian Bench at Ward Basin	51 N.	180
13	6–14–50	Three Valley Junction—Sunday Basin	51.5 N.	180
14	7–19–50	Three Valley Junction—Sunday Basin	51.7 N.	180
15	9– 1–50	Bowie Canyon	52.8 N.	179.6 E.
16	9–16–50	Bowie and Sitkin Canyons Junction	52.5 N.	178 E.
17	1–10–51	Pennant Trough	52.2 N.	175.5 E.
18	1–15–51	Aleutian Bench—Seymour Ridge	51 N.	178.2 E.
19	5–10–51	Aleutian Bench—Ward Basin	51.2 N.	179.8 E.
20	7–11–51	Rat Island Canyon	51.5 N.	177.8 E.

TABLE 3.—EARTHQUAKE CORRELATION

Structure	Trend	Number of Earthquakes
Aleutian Trench	E–W	0
Aleutian Bench	E–W	6
Oglala Trough	E–W	4
Buldir Depression	E–W	1
Bowie Canyon	E–W	1 or 2
Sitkin Canyon	N–S	2
Rat Island Canyon	N–S	1 or 2
Pennant Trough	N–S	1

Four seismographs with comparatively low magnification located at Attu, Adak, Unalaska, and the Pribilofs would result in excellent determinations. Microseismic activity, which is very high along the island arc, tends to obscure the earthquake waves on the seismograph records. Trial adjustment of the instrumental periods and sensitivities would be necessary until the best balance at each station was obtained. At present reliance is placed on very distant stations for recording the earthquakes, and it is doubtful if many of the lesser shocks have been picked up. The lesser shocks and macroseismic reports are needed for a good appraisal of the seismicity. Many earthquakes occurring to the eastward and westward of this section would no doubt be felt.

Despite the inadequacy of the epicenter locations for correlation with bottom relief, a preliminary attempt was made by plotting all available epicenter locations along the Aleutian Ridge on a small-scale chart (Pl. 2) to determine general trends, if any. Also the epicenters that fell within the 24,700 square-mile area of this section of the Aleutian Ridge and Trench were plotted on Plate 1 with their dates. In this case inferences must be made regarding earthquakes from known topography as distinguished from usual methods in poorly charted ocean areas of inferring some topographic features from the earthquake data. An idea of the seismicity of the Aleutian Ridge and Trench west of the Shumagin Islands may be had from Plate 2 on which all the epicenters are shown. The tendency of the epicenters to appear to align along east-west and north-south lines is due to the position determinations which were usually expressed to the nearest degree or half degree of arc. The locations are analysed as follows:

Location	Number of epicenters	Percentage
South of the trench	40	12
In the trench	24	7
South insular slope above 3,000 fathoms	124	40
Insular shelf	77	25
North insular slope	45	15
Bowers Ridge	4	1
	314	100

In view of the buckled appearance of the ocean bottom, it is not surprising to find considerable earthquake activity south of the bottom of the trench. Many scientists believe that earthquakes are associated with tension and shear stresses in the earth's crust. The southern edge of the Aleutian Bench lies about 10 miles north of the trench, and the entire zone between the foot of the insular slope (2000 fathoms) and the bottom of the trench ranges from 20 to 40 miles in width.

It would then only be necessary to move the epicenters that scatter along the southern slope between the south insular shelf and the trench a maximum of about 40 miles to align them all at the foot of the insular slope. That would place them in a zone in which the physiography indicates active diastrophism. This would not be too great a move since the locations are believed to be accurate within plus or minus half a degree of arc. Likewise, the 40 per cent that plot on the north insular slope and the insular shelf might be presumed to be properly associated with the tensional or shear zone marked by the volcanic arc.

Earthquakes known to have occurred in the area of Plate 1 are listed in Table 2.

Despite the inaccuracy of the locations there seems to be a fairly definite alignment along east-west structural trends. Since Bowers Ridge is notably nonseismic, the two near-by epicenters are related to Bowie Canyon. However, earthquake No. 6 could be associated with the structure underlying the Semisopochnoi Volcanoes, and earthquake No. 15 to some unsurveyed feature to the northward. Table 3 shows the number of earthquakes that may be associated with the main structural features.

There is thus sufficient indications of more accurate correlation between bottom relief and earthquakes along the rim of the Pacific to warrant further practical work along these lines.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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EVIDENCE OF PLEISTOCENE MAN IN DEATH VALLEY, CALIFORNIA

By Thomas and Lydia Clements

Abstract

It has long been known that there was a lake in Death Valley during the Pleistocene (Lake Manly), but, because the evidence of its presence seemed meager, its age had been put at Tahoe (early Wisconsin). Later studies have suggested that the lake may have had two major stages as did Lakes Bonneville and Lahontan: the first during Tahoe time, and the second during Tioga (late Wisconsin) time. The second stage, represented particularly by Manly Terrace, the largest terrace remnant now known in the valley, is correlated with the Provo and Dendritic Terrace stages of the above-mentioned lakes.

On Manly Terrace several hundred crude artifacts have been found, forming an integral part of the stone pavement covering the surface. These are principally scrapers, with a few gravers, drills, and rude blades. They are made of materials occurring in the vicinity: rhyolite, chert, jasper, chalcedony. Obsidian is conspicuous by its absence. The workmanship is most primitive, many are waterworn, and all are highly patinated with desert varnish as are the other stones of the desert pavement.

In the writers' opinion early man made and used these artifacts when Lake Manly stood at this lower level. This would have been during the Tiogan subage of the Wisconsin age of the Pleistocene epoch.

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Introduction

Death Valley lies in eastern California between 35°30′ and 37° north latitude and 116°30′ and 117°30′ west longitude. It has a general northwest-southeast trend and is 130 miles long by 5 to 20 miles wide. It is easily accessible by several paved highways.

Death Valley is one of a number of structural troughs in the Great Basin area, differing from most of the others only in its greater depth and larger drainage area. Its lowest known point, west of Badwater in the southern part of the valley (Fig. 1), is 282 feet below sea level; the highest point, Telescope Peak in the Panamint Mountains to the west, is 11,328 feet above sea level. Thus the maximum relief is more than 11,600 feet.

Drainage into the valley comes from the ranges bordering the depression and from the Amargosa Desert to the east (Fig. 1), where the Amargosa River flows southerly through its own basin before making a turn of 180° to enter the south end of Death Valley. At times in the past the Mojave River also drained into the valley (Campbell *et al.*, 1937, p. 15).

Under present conditions of a mean annual rainfall of 2 inches, summer temperatures that

have reached a recorded 134° F., and a humidity that occasionally is zero, there is no accumulation of water in the basin. A short segment of Salt Creek in the central part of the valley has a permanent stream (Fig. 1), and several fairly large springs flow the year around. The water from all of these disappears into the sediments that fill the depression. A small pool of salt water remains in the lowest part of the valley throughout the year, but there is no annual increment, and the level fluctuates within rather narrow limits.

These conditions differ from those of the relatively recent geologic past when the climate was more moist and considerably colder in the Great Basin (Antevs, 1948, p. 170–172). During this time lakes existed in many of the now desert basins of the area including Death Valley (Hubbs and Miller, 1948, p. 77–88).

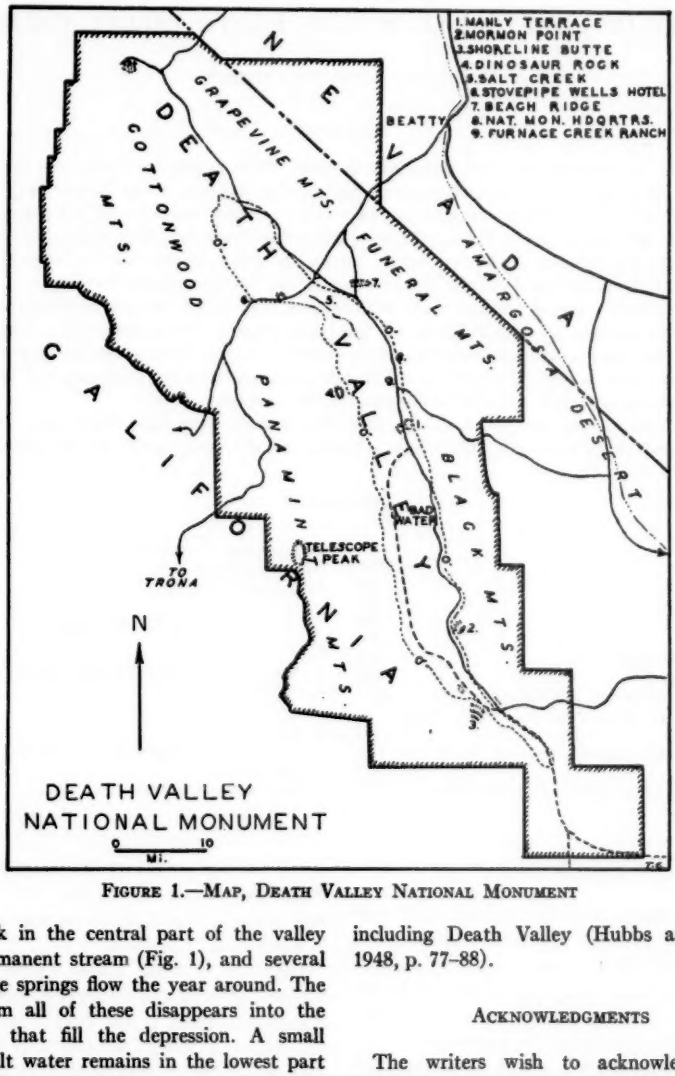


FIGURE 1.—MAP, DEATH VALLEY NATIONAL MONUMENT

ACKNOWLEDGMENTS

The writers wish to acknowledge their indebtedness to the many people who helped them in this project. Particular thanks are due Mr. T. R. Goodwin, Superintendent, Mr. L. Floyd Keller, Park Naturalist, and Mr. E. E. Ogston, Chief Ranger, all of Death Valley National Monument. Miss Ruth De Ette

Simpson, Assistant Curator of the Southwest Museum, Dr. Jesse Nusbaum, Chief Archeologist of the National Park Service, and Mr. Louis Caywood, Regional Archeologist of Region Four of the Service, visited the site and examined the artifacts. Mr. M. R. Harrington, Curator of the Southwest Museum, also examined the artifacts; he, Miss Simpson, and Mr. Montgomery Budd read the manuscript. Thanks are also due the Southwest Museum for allowing Miss Simpson time for work in the field. Dr. William H. Easton, Professor of Geology at the University of Southern California, made the photographs of the artifacts. The writers further wish to express their gratitude to Mrs. George Palmer Putnam of Stove Pipe Wells Hotel, to Mr. Joe Daley of Furnace Creek Ranch, and to a host of other residents of the valley whose kindness made their stay a very pleasant experience.

Lake Manly

It has long been accepted that there was a lake in Death Valley during the Pleistocene epoch. Gilbert showed such a lake on a map in his classic paper on Lake Bonneville (Gilbert, 1890, Pl. II), although he did not mention it in the text, and the lake as shown is far larger than present facts warrant. The first convincing evidence of the lake was given by Noble (1926, p. 69–70), and the name "Lake Manly" was suggested by Means (1932, p. 76) in honor of one of the two men who led the Bennett-Arcane party of Forty-niners to safety. Blackwelder (1933, p. 464–471) described the lake in detail and confirmed the name suggested by Means. More recently Miller (1943, p. 68–78) described a relict fauna of the lake, and he and Hubbs gave a general discussion of the relationship of Lake Manly to other more or less contemporaneous bodies of water in the Great Basin (Miller, 1946, p. 43–53; Hubbs and Miller, 1948, p. 77–88).

The dimensions of Lake Manly as given by Blackwelder (1933, p. 468) were approximately 90 miles long by 6–11 miles wide, with the elevation of its surface at maximum extension as approximately 300 feet above sea level. This would have given it a depth of almost 600 feet, if there have been no appreciable changes in elevation of the basin since the Pleistocene, as the lowest part of the valley today is 282 feet below sea level. Because of the few remnants of terraces found, and the apparent lack of beach ridges, Blackwelder concluded that these had been largely destroyed by erosion and that the lake must have been of considerable antiquity. He placed it, therefore, in the Tahoe or early Wisconsin (Iowan) subage of the Pleistocene (Blackwelder, 1933, p. 469–470).

On the writers' first trip to Death Valley in 1927, shore lines cut on a basaltic mass in the southern end of the valley (now known as Shoreline Butte) were pointed out by William Morris Davis as evidence of the former presence of the lake. On subsequent trips more and more shoreline features were seen. However, not until 3 months were spent in the valley in the spring of 1950 did the abundance of evidence become manifest.

The principal objective of the 3 months' stay was not a study of Lake Manly, but rather research on the Quaternary volcanics of Death Valley, and a search for evidence of early man in the area. But, inevitably, observations of shore lines and other phenomena were made, since many of the volcanic masses that were studied and sampled lay within the limits of the former lake. Furthermore, there was opportunity to see all parts of the valley at various times of day. It was astonishing to see features stand out sharply under one set of light conditions and vanish under another. Thus, in addition to features actually traversed, others were observed from a distance.

Beach ridges have now been recognized in the valley, and one of them, known for some time to Park Service personnel, is cut by the paved road from Furnace Creek Ranch to Daylight Pass (Fig. 1). This slightly eroded ridge is perhaps a quarter of a mile long and is composed of typical, waterworn beach gravel. Others, more eroded, are in the same locality but lower. The writers observed additional beach ridges or gravel bars in the south end of the valley extending for several hundred yards from the northwest end of Shoreline Butte. These also are made up of waterworn

pebbles and show dissection. Both occurrences are somewhat above sea level.

Wave-formed terraces are more widespread than was formerly believed. Although some were seen only from a distance, many were observed at close hand. Since most of the latter were cut in volcanic rock, they testify to fairly long stands of the lake at these levels. Such terraces were observed on the basalt hills on both sides of the highway approximately 4 miles east of Stove Pipe Wells Hotel, as well as on a dissected fan remnant in the same locality. Dinosaur Rock, a diabase ridge across the valley from Furnace Creek Ranch, shows at least two benches. Red Buttes, two cinder cones in the southern part of the valley, also show two distinct terraces; since they rise only 120 feet above sea level, they must have been submerged at times (Fig. 1).

The northerly side of Shoreline Butte is marked by 10 and possibly 12 benches. Some are quite narrow and may be the result of slumping in the loose basalt boulders that cover the slopes. Others are definitely wave-cut terraces. As it is at the south end of the valley, where it would have had the full force of waves generated by winds sweeping the entire length of the lake, Shoreline Butte would be expected to have a more extensive record than any other locality (Fig. 1).

On the east side of the valley not far from Shoreline Butte, a series of basalt outcrops show narrow benches, and Mormon Point, a little farther north (Fig. 1), is distinctly terraced. These latter terraces are cut in an old alluvial fan, and considerable wash from above has spread over them. In one place, flat-lying lake beds overlie tilted alluvial-fan material.

Manly Terrace is on the east side of the valley, only a few miles south of Furnace Creek Ranch (Fig. 1). The mass of diabase on which it is in part cut shows three narrow benches on its valley-ward side. Manly Terrace itself is one of the widest terraces observed. Above it are the eroded remnants of at least two higher benches, cut on alluvial-fan material. The lowermost bench of this whole series is continued to the southwest across the road. Other terraces were seen farther north, but no particular observations were made upon them.

Elevations of the various terraces in the valley were determined with an aneroid barometer, checked both before and after readings where possible, with bench marks or other points of known elevations. Nevertheless, the elevations could not always be relied upon even within the limits of an aneroid, because of the sudden barometric changes that occur in the region. Furthermore, discrepancies might be expected in terrace levels as the result of crustal movements since the terraces were formed. Almost the entire west face of the Black Mountains, which border the east side of the south end of the valley, is a fresh fault scarp. Small scarps also cut the alluvial fans on both sides of the valley. Terraces, therefore, which may be correlatives in age, may show considerable differences in elevation.

The highest terrace elevations recorded were on Dinosaur Rock at 550 feet above sea level; on Shoreline Butte at 480 feet above sea level; on Mormon Point at 425 feet above sea level; and above Manly Terrace at 390 feet above sea level. There was s suggestion of a higher terrace on Mormon Point, but this needs confirmation. These elevations are all considerably higher than the 310 feet above sea level given by Blackwelder (1933, p. 468) as the highest level reached by the lake

PLATE 1.—MANLY TERRACE

FIGURE 1.—VIEW OF NORTHERN PART OF TERRACE FROM ABOVE

Note bedding exposed by erosion in wave-built portion. Front of terrace is cut on volcanics.

FIGURE 2.—MORE HIGHLY DISSECTED SOUTHERN PART OF TERRACE

Low hills immediately beyond and across highway are remnants of a lower terrace.

PLATE 2.—GRAVERS, SIDE SCRAPER, AND KEELED END-AND-SIDE SCRAPER

FIGURE 5a and 5b (DV:11-48).—DARK-GREEN CHERT GRAVER

FIGURE 6a and 6b (DV:11-47).—CHALCEDONY GRAVER

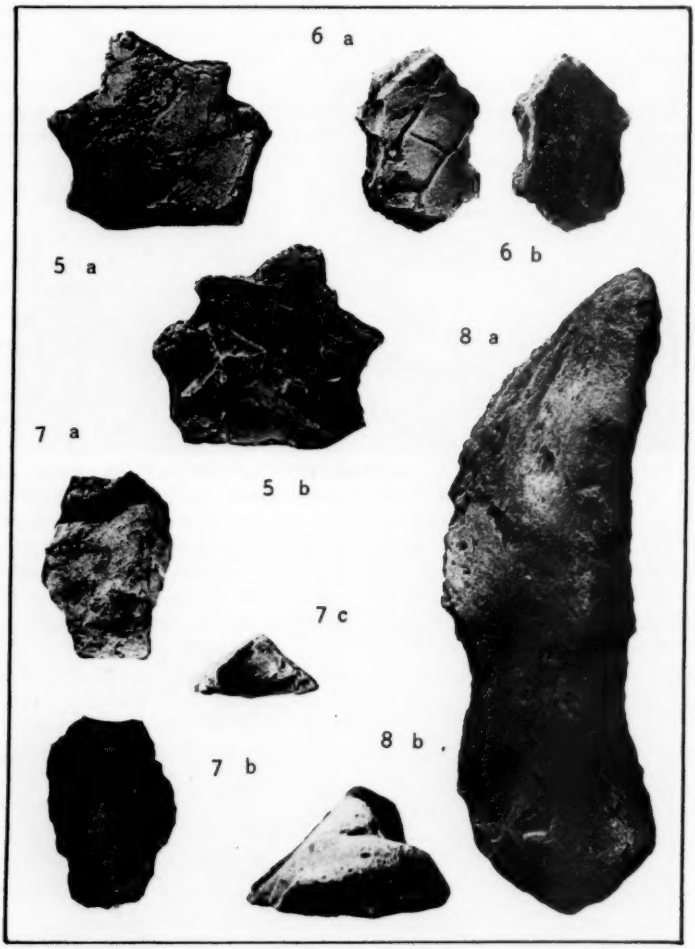
FIGURE 7a, 7b, and 7c (DV:11-42).—GREEN CHERT SIDE SCRAPER

FIGURE 8a and 8b (DV:11-20).—RHYOLITE KEELED END-AND-SIDE SCRAPER

FIGURE 1

FIGURE 2

MANLY TERRACE



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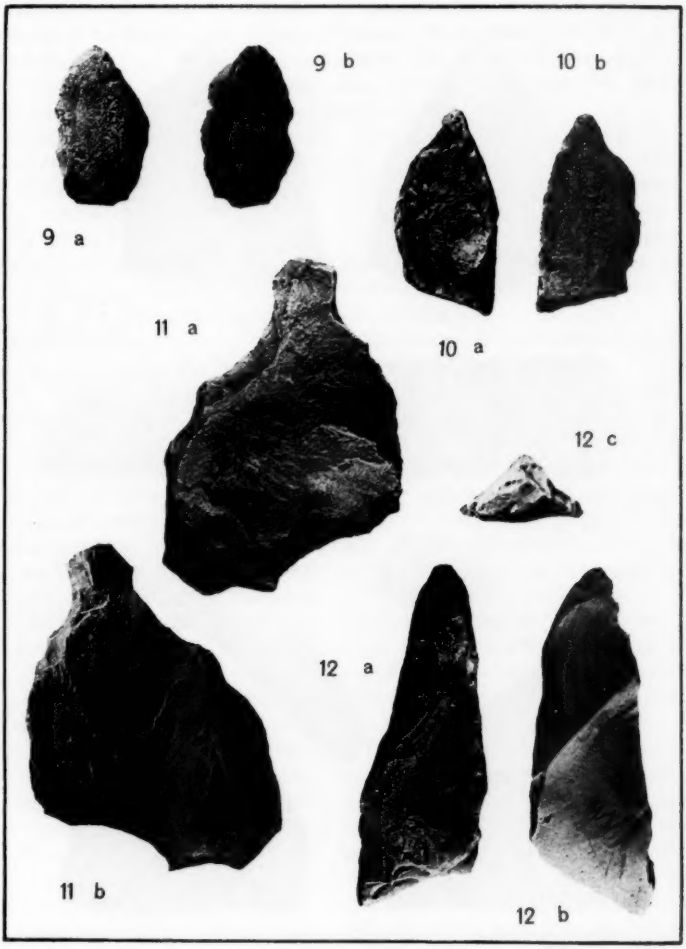

MICROLITHS AND DRILLS

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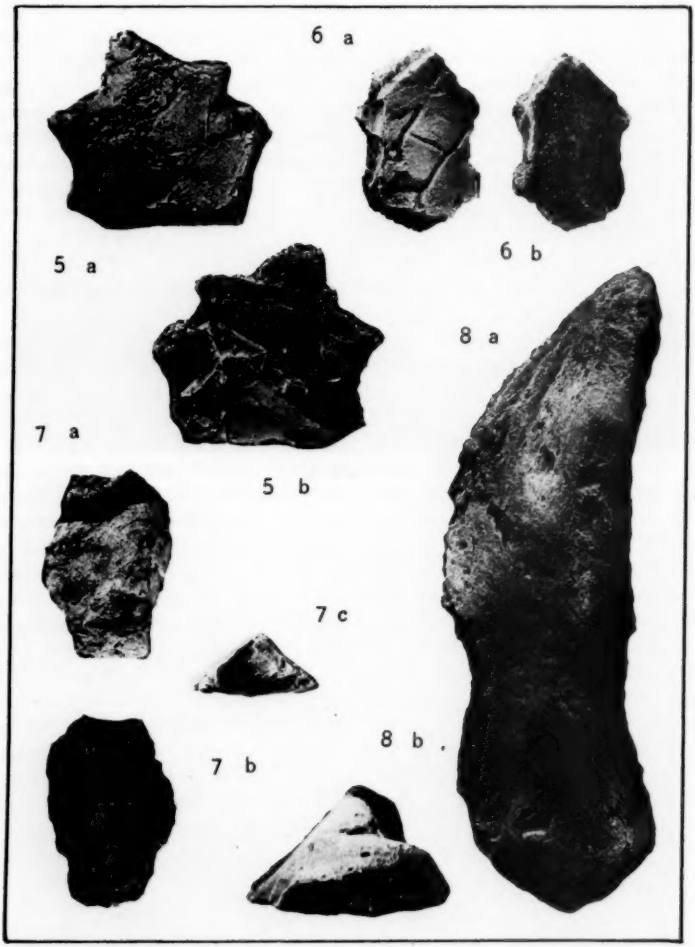
MANLY TERRACE



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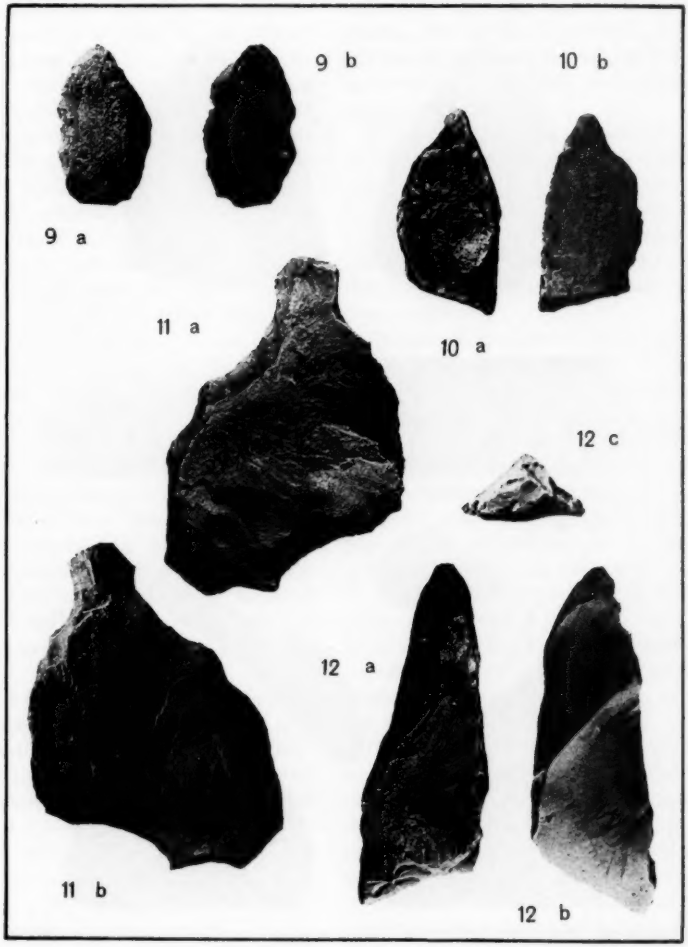
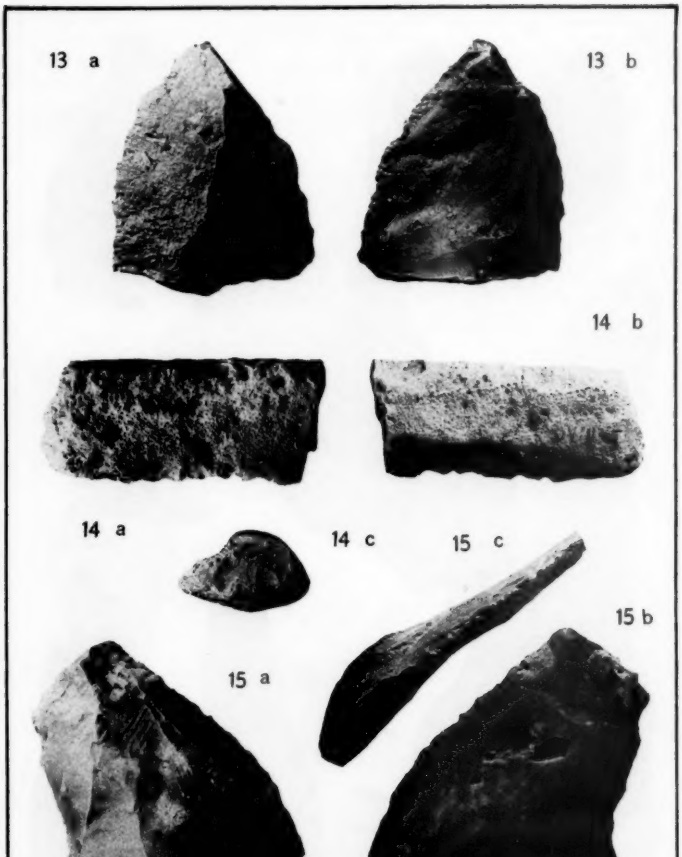


MICROLITHS AND DRILLS



KNIVES

Three possibilities must be kept in mind: (1) these are not terraces, but slumps or landslides, (2) the elevations determined by barometer may be incorrect, and (3) crustal movements may have caused a shifting of the terraces since their formation.

Barometric errors may account for some discrepancies, and faulting may account for others. Also, it may be difficult to prove that all the benches are actually wave cut. Nevertheless, it is significant that, on all the four higher slopes examined, benches were found well above the 300-foot level. This suggests that they actually are terraces, and that the lake, therefore, was deeper than postulated by Blackwelder. This calls for further search on other higher, resistant slopes.

The most interesting terrace of all, from the authors' point of view, is Manly Terrace (Pl. 1), named to further honor William Lewis Manly. It consists of two parts, each several hundred feet wide by approximately a quarter of a mile long, and separated by a deep gully. The lower edge of the terrace is approximately 200 feet above the road and has an elevation of 40 feet below sea level. The almost flat surface undulates slightly, rising gently to the more abrupt incline that marks the former wave-cut cliff and the transition to the next higher and older bench.

The surface is largely floored with a mosaic of angular, subangular, and subrounded rock fragments with an average maximum dimension of approximately 1 inch, forming a typical desert pavement. Cobbles and boulders of scoriaceous diabase from 6 inches to a foot in size and in some cases well waterworn, are scattered over the terrace, and an accumulation of much larger boulders of the same material marks the former lakeward margin. All the rocks on the surface are deeply colored with desert varnish, except where exfoliation has recently exposed fresh faces.

The lakeward portion of the terrace is cut on massive diabase, or on diabasic volcanic breccia. The landward portion is wave built. Erosion has exposed waterworn gravel, in part cross-bedded, underlying the pebble-floored surface of this portion.

Undoubtedly this is a wave-formed terrace, cut and built by the waters of Lake Manly during a stand either after it had receded from its maximum extent to a lower level or following a later rise. The width of the terrace, part of which is cut on resistant volcanics, is evidence that the lake remained at this lower level for a considerable time.

The present elevation of the terrace may not represent its original elevation. The block on which the terrace is cut is separated from the main mass of the Black Mountains by a recent fault, whose scarp forms the northeasterly boundary of Desolation Canyon. Manly Terrace and its associated higher and lower terraces are on the valley block, which has been lowered considerably with relation to the other block in Recent time, if the criteria of fresh fault features and almost nonexistent alluvial fans along the east side of the valley can be relied upon. It may, therefore, be the correlative of any of the lower terraces in other parts of the valley, or of a terrace now buried by alluvial fans or removed by erosion.

The writers believe that, if Manly Terrace is to be correlated with any of the terraces observed in other parts of the valley, it probably should be with one at 130 feet above sea level on Shoreline Butte. This terrace, approximately 300 yards wide, is the broadest observed in the southern area. Its relationship to other terraces at lower and higher levels is somewhat similar to that of Manly Terrace, although

PLATE 3.—MICROLITHS AND DRILLS

FIGURE 9a and 9b (DV:11-41).—RHYOLITE MICROLITH; A TINY POINTED SCRAPER

FIGURE 10a and 10b (DV:11-39).—RHYOLITE MICROLITH; SMALL SIMPLE DRILL

FIGURE 11a and 11b (DV:11-137).—RHYOLITE; HEAVY CRUDE DRILL

FIGURE 12a, 12b, and 12c (DV:11-44).—GREEN CHERT; COMBINATION SMALL POINTED SCRAPER AND DRILL POINT

PLATE 4.—KNIVES

FIGURE 13a and 13b (DV:11-4).—RED JASPER

FIGURE 14a, 14b, and 14c (DV:11-5).—CHALCEDONY

FIGURE 15a, 15b, and 15c (DV:11-51).—MOTTLED CHALCEDONY

more and higher terraces are recorded at Shoreline Butte. The difference in elevation of 170 feet may seem large, but crustal movements in the valley since the beginning of Pleistocene time probably are measurable in thousands of feet, which make this small movement after the Pleistocene seem relatively insignificant.

To correlate Manly Terrace with shore lines in other parts of the Great Basin seems hazardous. If Lake Manly was formed by overflow from Lake Panamint by way of Wingate Pass, as the end in a series of lakes formed by meltwater from Sierra Nevada glaciers of early Wisconsin (Tahoe) age as Blackwelder (1933, p. 468) and others have suggested, then there should have been but one lake, since at no later time did water in the other lakes reach a height sufficient to overflow into Death Valley.

However, lake levels in the Great Basin were not necessarily controlled only by melting ice, but in some cases by increased precipitation and cooler climate, the result of the southward shifting of the normal rain belt due to the presence of ice sheets over Canada (Antevs, 1948, p. 169–172). Death Valley's drainage area is one of the largest in the Basin and Range province (Thompson, 1929, p. 572). Conceivably, therefore, Lake Manly and the other lakes in the province fluctuated, and during more than one period the water level remained stationary for a relatively long time. The first rise of Lake Manly presumably coincided with the Tahoe glacial subage, when water overflowing from Lake Panamint was added to precipitation from its own catchment basin to give it its highest level. The second rise was probably contemporaneous with the Tioga or late Wisconsin subage when precipitation, aided by decreased evaporation, maintained the lake at a lower level. The senior author believes that Manly Terrace was formed at this later time and is the correlative of the Provo terraces of Lake Bonneville and the Dendritic terraces of Lake Lahontan (Antevs, 1948, p. 170).

Any physiographic evidence of a lake in pre-Wisconsin ages has long since been destroyed; however, the occurrence in the bottom of the valley of over 1000 feet of salt, now covered by sediment, suggests that such a lake or lakes existed. The water of Lake Manly was probably fresh for a time, but, with no outlet, became brackish and eventually salty, although this last condition may not have been attained until long after the waters had receded from Manly Terrace. There were fish in the lake (Hubbs and Miller, 1948, p. 83–84), and doubtless water fowl were abundant. Increased precipitation and the cooler climate resulted in a covering of forest trees on the mountains, and of brush and grass on the now bare lower slopes. Game was probably abundant, as indicated by the writers' recent find of an elephant tusk associated with beds of a presumably contemporaneous lake in the north end of the valley (T. Clements, 1952, p. 1324).

If man were in North America at the time, it is not unreasonable to believe he might have lived in this area where conditions were favorable. However, not all parts of the shore of this lake would have been accessible. Precipitous slopes in some places, and inhospitable, snow-covered mountains in others would have kept man from attempting to reach the shore in many places. Other parts of the shore, accessible then, may since have been destroyed by erosion or buried under alluvial fans. However, Manly Terrace, which in large part has been preserved, would have been readily accessible. It was here that evidence of man might be expected, and it was here that such evidence was found.

Archeology

General Remarks

One usually thinks of people in Death Valley as comparative newcomers. When the first white men came through the valley in 1849–1850, Indians were living in the bordering Panamint Mountains, who, unobserved, saw the pioneers. Since that time small groups of Panamint (or Shoshone) Indians have continued to live in the valley in winter, summering in the mountains as did their forefathers. The number at any one time probably has never been large; nevertheless over the long period of habitation many individuals have lived and died in the area, leaving traces of their culture behind them.

Death Valley, therefore, is relatively rich in Indian archeological material, although little

scientific work has been done on it. The considerable collection in the Monument workshop was made available to the writers for study and was cataloged by the junior author. The bulk of the artifacts, collected from 1933 to 1940 by boys of the Civilian Conservation Corps, H. D. Curry, former Acting Park Naturalist, and others associated with the National Park Service, came from 10 localities. The writers added 19 localities during their work in the area (L. Clements, 1951, p. 125). Still more are being found.

The collections are from all parts of the valley and from high in the bordering mountains. The types of localities range from sand dunes to springs, and from cave to lake terrace. Not only artifacts, but house circles and petroglyphs also testify to the earlier presence of man. The petroglyphs are found in many side canyons as well as in the valley proper, but their significance and by whom they were made are unknown. The artifacts indicate a broad range in cultures, from primitive to modern.

With these finds in mind it seemed natural to look along the shores of Pleistocene Lake Manly for evidences of still earlier man, especially since abundant ancient artifacts had been found in Pinto Basin (Campbell *et al.*, 1935, p. 23); on the shores of Pleistocene Lake Mohave (Campbell *et al.*, 1937, p. 32); and in the Little Lake area (Harrington, 1948, p. 116–118). This search was rewarded on Manly Terrace.

The first artifact (Fig. 2, 1a; 1b) was found by the junior author on the front portion of the broad terrace. This was a rudely chipped, flat side scraper (DV:11-1)[1] heavily covered with desert varnish. The workmanship was crude, but the clearly visible flaking indicated that the tool was definitely man-made.

Two crude side scrapers (DV:11-2 and DV:11-3), about 2 by 2½ inches and very thin, and a heavily patinated dark-red jasper blade (DV:11-4) (Pl. 4, fig. 13) which would have been serviceable as a scraper or, on a haft, as a knife, were found the same day. The blade was very simple in workmanship, well shaped, and chipped on alternate edges. A 1½-inch section of a chalcedony blade (DV:11-5) (Pl. 4, fig. 14), evenly worked on both sides of one edge, was also in the initial find.

Park Naturalist L. Floyd Keller was immediately notified of the discovery. Later Mr. M. R. Harrington and Miss Ruth De Ette Simpson, both of the Southwest Museum of Los Angeles, examined the assemblage and stated that in their opinions the objects were definitely man-made (Personal communications).

More than 500 artifacts have now been found which will be housed in the Monument workshop pending the building of a much-needed museum in Death Valley. It is hoped that duplicate collections may be placed in the National Museum and in the Southwest Museum.

Occurrence

The artifacts form an integral part of the smooth, highly varnished stone mosaic which covers the surface of the terrace in most places. They are more concentrated in some spots than others, but there is no apparent pattern, such as fire circles or camp sites. A possible fire circle near the upper margin of the terrace is, in the opinion of the writers, much later, and Nusbaum, Senior Archeologist of the National Park Service, agrees (personal communication). There are numerous scattered groups of stones whose shape suggests hammerstones and manos, but they are so like much native water-worn rock that it is extremely difficult to determine whether or not any of them were used by man.

The rocks of the stone pavement, including the artifacts, form a thin veneer over the underlying finer-grained lake sediments. This suggests that the artifacts were in use when the waters of the lake washed the terrace. The fluctuating level covered camp sites from time to time, and the wash scattered the crude tools and incorporated them into the beach shingle. Later wind action removed the sand, leaving the stone pavement. Any sites above the upper limit reached by the lake at this time probably have been masked by alluvium.

[1] Numbers are those assigned to the artifacts in the Catalog of the Indian Collection of the Death Valley National Monument, prepared by the junior author.

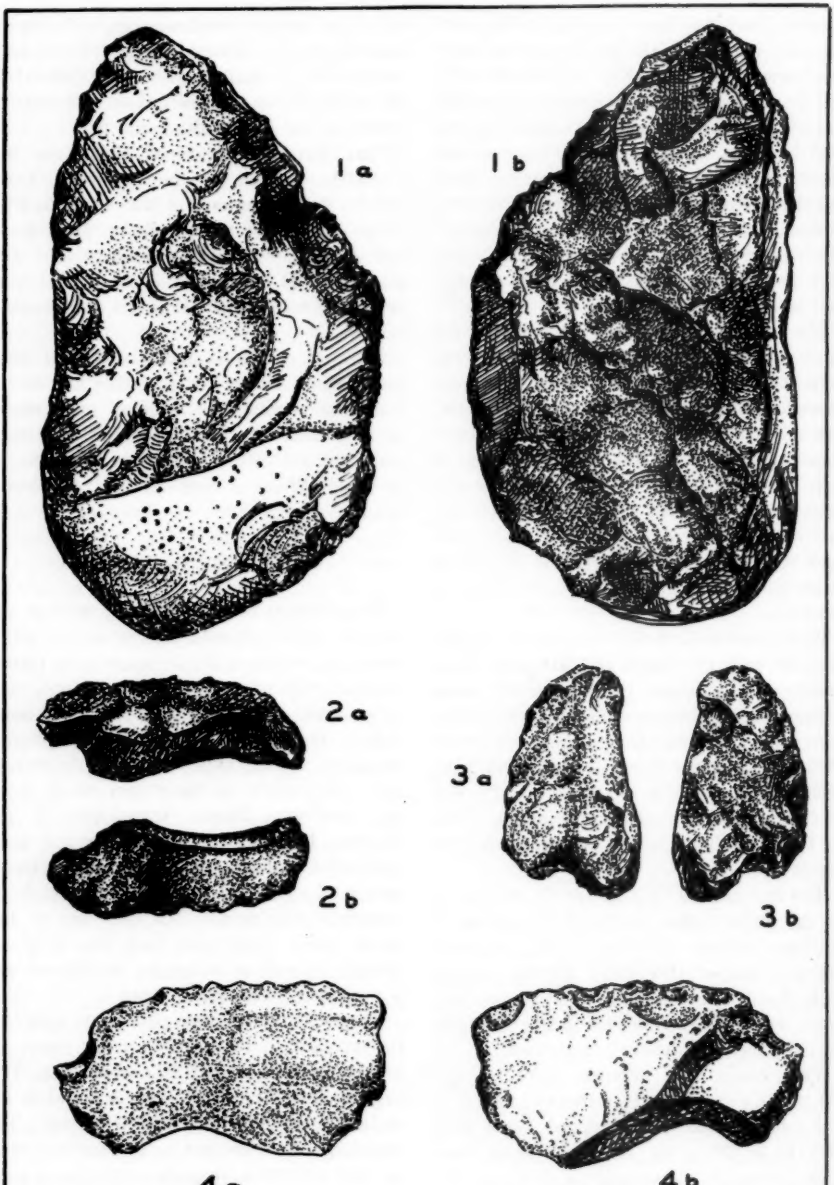


FIGURE 2.—SIDE SCRAPERS
1a and 1b (DV:11-1) RHYOLITE
2a and 2b (DV:11-121) RHYOLITE
3a and 3b (DV:11-123) RHYOLITE
4a and 4b (DV:11-49) GREEN CHERT

Types and Abundance of Artifacts

Extreme simplicity and crudeness of workmanship characterize the entire collection of artifacts. Most of them show only a minimum of fashioning. Another impressive feature is the heavy patina of desert varnish which covers them all. In the majority of cases the artifacts are made of rhyolite, although green chert, chalcedony, and dark-red jasper were also used. These rocks and minerals are of local occurrence, abundant on the ridge above the terrace. No obsidian, either in the natural state or as artifacts, has been observed. Pitchstone occurs in the vicinity but for obvious reasons was not used. In almost every case the patina is so thick that only with difficulty can the material be identified.

Scrapers of diverse types, shapes, and sizes are the most common artifacts found. A few gravers occur, but the more usual form is a combination scraper-graver. Drills and blades are in the minority. Only one spear point (DV:11-100) has been found, and it is of much more finished workmanship and shows less patination than the assemblage as a whole. The authors believe it is of later date, possibly belonging to the same age as the fire circle.

One weathered piece of vesicular diabase of mano size and flattened-ovate shape was found. Mr. Harrington and Miss Simpson pronounced it a grinding stone (personal communication). In addition a few definite hammerstones were collected. Other rocks could have been used for the same purposes, but most of them were questionable and have not been included in the collection. Nothing even vaguely resembling a metate was discovered.

Cores, large and small, of dark-green chert with a heavy brown patination, are rather common. Most of them were from the larger, flatter portion of the terrace. Red jasper chips and cores were more abundant in concentrated areas, generally higher on the terrace. Some of the jasper chips may be the result of natural weathering, but in many cases they appear to be man-made and are possibly more recent.

Comparison with Artifacts from Other Localities

It would be expected that relics of early man found in Death Valley should be similar to those recorded from such relatively near-by sites as Pleistocene Lake Mohave, Pinto Basin, and the more recent find at Little Lake. The most interesting, and one of the most striking, differences is the absence of obsidian in the Manly Terrace collection and its presence in the materials from the other sites, particularly Little Lake.

Obsidian is not known to occur in Death Valley, where the only volcanic glasses are pitchstone and perlite, neither of which is suitable for fashioning. However, it is abundant near Little Lake in Owens Valley, especially at the Coso quarry approximately 100 miles to the west (Harrington, 1951, p. 15–18). Little Lake artifacts are overwhelmingly of obsidian, and some obsidian artifacts occur in the Lake Mohave and Pinto Basin assemblages. Its absence from Lake Manly, therefore, is surprising, especially since very finely worked modern Shoshone points of obsidian are found in Death Valley. Three possibilities suggest themselves: (1) the fine tool-making qualities of obsidian had not yet been recognized at this early date in North America; (2) the Owens Valley obsidian occurrence was unknown at the time Manly Terrace was inhabited; (3) the deposit was known to local inhabitants, but there was no trade between the two areas. The writers believe that either (1) or (2) is more logical than (3). Dr. Alex D. Krieger has stated (personal communication) that his experience has been that the earliest assemblages contain no obsidian. This would favor the first possibility.

From the point of view of variety of implements and worked types, those of Manly Terrace are much less comprehensive than those from the other three sites. No distinctive points such as Pinto, Mohave, Silver Lake, or Folsom have been found. In fact no projectile points are known, except the one spear point mentioned above, which the writers believe to be later than the Manly Terrace culture as a whole. In this opinion Nusbaum concurs (personal communication).

Except for a comparatively few artifacts, including a mottled chalcedony blade, (DV:11-51) (Pl. 4, fig. 15), and some of the red jasper, most of the worked pieces from Manly Terrace are much more primitive, and have a heavier patination than those from the other sites.

The exceptions may be somewhat younger, or perhaps the character of the material may make the difference in appearance. Jasper lends itself better to sharp, clean flaking. The rhyolite and chert implements are generally characterized by primary flaking done in an extremely crude manner.

The lack of metates and of definitely identifiable manos is also significant. These were found at the other three sites, and were to be expected on Manly Terrace. Perhaps the site represents only temporary hunting or fishing camps occupied for relatively short intervals, over a long period of years. Or possibly these people did not grind seeds, but lived entirely on the fruits of the chase.

The logical conclusion is that the Lake Manly site was inhabited at an earlier date than the Lake Mohave, Little Lake, and Pinto Basin sites.

Other Possible Comparable Sites in Death Valley

Having found such a rich accumulation of artifacts left by primitive man on Manly Terrace, the authors examined other lake terraces of comparable age in Death Valley. None of those studied has given evidence of habitation.

Mormon Point, with high and well-defined terraces in the southeastern part of the valley, seemed a natural place to look. However, nothing was found on the surfaces of the terraces examined. The topographic setting perhaps explains man's absence from this locality. The promontory rises steeply on the side away from the lake to the highest and most rugged part of the Black Mountains. With no broad beach on the lake side, access would have been difficult except by raft.

Neither did the upper terraces on Shoreline Butte in the south end of the valley yield evidence of man, and again the topography is the possible explanation. Pleistocene alluvial-fan material connects the Butte with the Owlshead Mountains, but these are relatively rugged and inhospitable and doubtless acted as a barrier.

The lowermost terrace on the northerly end of Shoreline Butte and the surface of an adjacent beach ridge yielded a number of scrapers and worked flakes, as did the lowest terraces on Red Buttes, a pair of cinder cones, a short distance to the north. These artifacts are similar to a scraper and a few chips found associated with house circles and cairns on the lowermost terrace in the Manly Terrace area at an elevation of 175 feet below sea level. None of these artifacts shows the patination nor the waterworn appearance characteristic of the Manly Terrace implements. The writers believe these belong to a younger culture.

All other sites in Death Valley represented by material in the Monument workshop, or visited by the authors (L. Clements, 1951, p. 125–128), showed a wider range of materials, a greater variety of tools, and more finished workmanship. Artifacts from these sites do not have the heavy patina of desert varnish, nor do they show the waterworn features of those from Manly Terrace. There seems to be little question that the Manly Terrace material is earlier.

Probable Age of the Manly Terrace Artifacts

Both geological and archeological evidence have a bearing on the determination of the age of the artifacts from Manly Terrace. (1) Since the artifacts are an integral part of the stone pavement flooring the terrace, and most of them are waterworn as are the other stones, it is difficult to conceive that they are different in age. The terrace is unquestionably wave cut and built, and must have been formed when Lake Manly stood at the original level of Manly Terrace. This is not the highest, although it is the most extensive terrace known at any level. Other Pleistocene lakes in the Great Basin, notably Bonneville and Lahontan, show the same pattern of terracing, and it therefore seems logical to correlate Manly Terrace with the similar terraces in these two lakes: Provo and Dendritic terraces, respectively. Antevs (1948, p. 171) has indicated that the Provo lake level coincided with the Tioga (Mankato) subage of the Wisconsin glacial age, which he dated as approximately 20,000 years ago.

Recent work on the Carbon 14 content of trees overridden by the Mankato ice sheet in the Great Lakes region places the Mankato

11,000 years ago (Flint and Deevey, 1951, p. 282). Without questioning the accuracy of the methods employed, it must be emphasized that the Carbon 14 method of dating is based on the assumption that the rate of formation of Carbon 14 has remained uniform throughout the time that is being determined (Libby, 1952, p. 32). Even the checking of established dates 3000 and 4000 years ago does not prove the assumption correct for time prior to those dates. It is therefore the opinion of the senior author that Manly Terrace was formed approximately 20,000 years ago, a point on which Antevs formerly agreed (personal communication). Regardless of which figure is used, the time must still be considered as Pleistocene.

(2) The coating of desert varnish is very deep on most of the artifacts and is the same as that found on the rest of the stones of the pavement. This feature has been noted by the authors on other terraces throughout the desert area, including those bordering the Colorado River, which are definitely Pleistocene. The patina is lacking on the Recent gravels and stone pavements, and thus the latter can readily be distinguished from the older (Pleistocene) ones. The indication again is that the stone pavement of which the artifacts form a part is Pleistocene.

(3) The artifacts themselves exhibit: (a) very crude workmanship; (b) limited variety of tools; (c) preponderance of early scraper types; (d) exclusive use of materials immediately at hand; (e) absence of obsidian implements; (f) lack of specialized points, such as Folsom or Lake Mohave; (g) lack of grinding stones other than the one mano-like specimen; and (h) lack of correspondence with artifacts from other California sites. All these suggest an early culture, older than those previously known from the general vicinity.

Conclusions

The authors conclude that the Manly Terrace artifacts were used by a primitive hunting people on the shore of Lake Manly during the Tioga subage of the Wisconsin age of the Pleistocene epoch. This was possibly before people in the southwest established permanent camps. It is significant that knowledge of man's habitation of Death Valley has been pushed from historic times back to a time when man was a newcomer on the North American continent. This is a distinct challenge for more comprehensive investigation, not only of Death Valley, but of the southwestern desert area as a whole.

Descriptions of Artifacts

The junior author presents the following classification of Manly Terrace specimens as a tentative identification of tools which are part of this early California culture horizon. Further investigation of comparable sites will establish this newly recognized stone complex.

This assemblage does not contain all the specimens collected and numbered, but is representative of the definitely worked material. In addition, there is much material that is extremely worn or of dubious origin, and, although it was probably man-made or used, it is not deemed of sufficient added significance to be described at this time.

Unless otherwise noted, all artifacts listed are uniface.

Side-Scrapers

DV:11-1 (Fig. 2, 1a; 1b); rhyolite; flat, large heavy flake; 3.7″ by 2″ by 0.7″; crude primary flaking on one edge; heavy patina.

DV:11-19; rhyolite; crude, heavy, long and narrow; 4.3″ by 1.3″ by 1″; primary flaking on one edge.

DV:11-29; chalcedony; broad leaf-shaped; recent concave break on top; 2.5″ by 1.5″ by 0.5″–0″; heavy patina.

DV:11-49 (Fig. 2, 4a; 4b); light-green chert; a beautiful, waterworn piece; natural concave top surface; 1.9″ by 1″± by 0.2″–0″; primary flaking on one edge and around point, on bottom surface; recent break on one side; brown patina.

DV:11-62; red jasper; fragment of large flat flake; 2.5″ by 1.6″ by 0.6″; broad primary flaking.

DV:11-66; rhyolite; angular pebble, shaped for use; 1.8″ by 1.5″ by 0.8″–0″; flaked on one edge; very worn.

DV:11-70; red jasper; rudely shaped, used piece; 2″ by 1.3″ by 1.1″±; flaked on top surface of one edge and bottom of opposite edge.

DV:11-73; red jasper; small core shaped to scraper edge on one side; 1.9″ by 1.4″ by 0.7″; primary flaking.

DV:11-75; red jasper; roughly shaped, small; 1.5″ by 1.4″ by 0.7″; primary flaking on both top and bottom, with light retouch on one edge of bottom; heavy patina.

DV:11-92; rhyolite; small, wedge-shaped; 1.3″

by 0.7″ by 0.7″–0″; slight secondary flaking on one edge; heavily patinated.

DV:11-107; light-green chert; naturally curved flake; 2″ by 1.2″ by 0.2″±; one edge flaked; heavily patinated.

DV:11-108; light-green chert; natural piece, smooth oily surface; 2.2″ by 0.7″ by 0.7″–0″; curved edge slightly worked.

DV:11-121 (Fig. 2, 2a; 2b); rhyolite; small, fits nicely in fingers; 1.6″ by 0.5″ by 0.4″–0″; secondary flaking on top edge of one side.

DV:11-123 (Fig. 2, 3a; 3b); rhyolite; small, flat flake; natural surface top and bottom; 1.4″ by 0.8″ by 0.2″; concave end; primary flaking on one edge; weathered.

DV:11-144; rhyolite; small, heavy, natural fragment; 1.9″ by 0.5″ by 0.7″; one worked edge faintly visible.

End-and-Side Scrapers

DV:11-8; rhyolite; broad leaf-shaped; 2.8″ by 1.6″ by 0.5″–0″ on both sides and end; broad primary flaking.

DV:11-13; rhyolite; small, flat, natural fragment; 1.4″ by 1.3″ by 0.3″–0″ on one side; one side worked, and slight secondary flaking on rounded point and end; weathered.

DV:11-15; rhyolite; small, flat triangular flake; 1.8″ by 1.4″ by 0.2±″; top surface shows broad even flaking on end and side; weathered.

DV:11-24; gray chert; small, chunky, natural wedge shape; 1.3″ by 1.1″ by 0.6″; slight flaking along top edge of one side, with end showing use; extremely heavy desert varnish.

DV:11-110; rhyolite; flat leaf-shaped with both ends slightly pointed; 2.8″ by 1.4″ by 0.3″±; top surface rudely worked on both ends and one side; weathered.

DV:11-126; rhyolite; thick wedge easily held in fingers; 1.8″ by 1.4″ by 0.6″–0″; very simple flaking on one side, end and point on top surface, with slight, even flaking on alternate end surface.

Pointed End-and-Side Scrapers

DV:11-21; rhyolite; a heavy crude tool; both ends pointed, with high natural center ridge; 3.8″ by 1.5″ by 1″–0″ on both side edges; flaked side and one end on bottom surface, opposite end on top surface of edge.

DV:11-88; rhyolite; flat elongated triangular shape; one side convex; top and bottom natural surfaces; 2.5″ by 1.2″ by 0.4″; worked on flat end and top surface of curved edge.

DV:11-117; rhyolite; small spade-shaped flake; 1.9″ by 1.4″ by 0.3″; evidence of flaked edges on end (lower edge) and on both sides, one on top surface and the other on lower surface; weathered and heavily patinated.

DV:11-128; rhyolite; small, thin triangular flake; 1.5″ by 1.4″ by 0.3″–0″; flaked sparingly on lower edge of one side and around point.

Convex Scrapers

DV:11-22; rhyolite; small triangular; 1.7″ by 1.5″ by 0.4″–0″; roughly worked on top surface of convex edge; weathered.

DV:11-46; rhyolite; very small; rounded on top surface, ending with pointed tip; under side concave; 1.3″ by 0.7″ by 0.5″; even flaking on top surface of convex side and tip; heavy patina.

DV:11-84; jasper; fragmentary, with sharp convex edge; 1.9″ by 0.9″ by 0.6″–0″; top surface roughly worked.

DV:11-97; quartz; tiny, flat oval flake; 1.3″ by 0.9″ by 0.2″; slightly worked along convex side and slightly pointed end; deep orange patina.

DV:11-104; rhyolite; thick wedge-shaped; 1.8″ by 1.6″ by 0.8″–0″; crude flaking on thin edge.

DV:11-115; rhyolite; fragmentary pebble; 1.8″ by 1.7″ by 1″–0″; one edge worked; heavy desert patina.

DV:11-116; rhyolite; flattened round pebble; natural surface; 1.5″ by 1.6″ by 0.4″–0″; worked on alternating edges; weathered.

DV:11-120; rhyolite; a small, irregular flake, easy to hold; 1.6″ by 1.3″ by 0.5″–0″; concave top and flat bottom unworked, three sides flaked on top surface.

DV:11-131; rhyolite; an angular fragment; 1.8″ by 1.4″ by 0.7″; concave edge shows evidence of use.

Concave (and in Combination) Scrapers

DV:11-6; rhyolite; heavy, flat, chopper type, with concave cut in one side; 3.4″ by 2.7″ by 0.9″–0″; crudely flaked on alternate sides of two edges.

DV:11-11; rhyolite; end-and-side combination; small, flat rectangular with two slight points on one end; 1.9″ by 1.3″ by 0.4″–0.1″; concave cut on one side, opposite slightly convex worked top surface; end worked on under surface.

DV:11-17; rhyolite; wedge-shaped concave side-scraper; 2.2″ by 1.4″ by 0.8″–0″; one edge worked.

DV:11-23; rhyolite; small, heavy end-and-side combination; 1.7″ by 1.5″ by 0.6″; ends worked on alternate edges; both slightly concave sides worked on top surface.

DV:11-26; rhyolite; heavy wedge-shaped flake, end-and-side combination; 2.4″ by 2″ by 0.5″–0″; broad concave cut flaked from top on one side; secondary flaking on top edge of end.

DV:11-27; rhyolite; crude, wedge-shaped; 2.1″ by 1.6″ by 0.6″–0″; rude concave cut on one side.

DV:11-28; red jasper; a natural flake; 2.3″ by 1.7″ by 0.3″; concave cut flaked from one side (top surface); natural weathered top surface.

DV:11-35; rhyolite; very small end-and-side combination, concave end; opposite end broken; 1.2″ by 0.6″ by 0.3″–0″; fine, even flaking on side and end; bottom flat, with concave top rising from cut on end.

DV:11-36; rhyolite; combination pointed end-and-concave; worked top surface, natural flat bottom; 1.8″ by 1.4″ by 0.4″; pointed ends and one side worked broadly on top edge, the alternate edge worked slightly on opposite side.

DV:11-89; rhyolite; heavy leaf-shaped flake; flat bottom and top, latter slightly concave; 2.3″ by 1.4″ by 0.6″; concave side rudely flaked on top edge; opposite convex edge retouched on bottom; point slightly worked.

DV:11-91; rhyolite; long, narrow flake; combination scraper-and-reamer, 2.2″ by 0.6″ by 0.3″±;

evenly flaked on upper concave edge and dull point; natural surface top and bottom.

DV:11-113; rhyolite; almost round, thin natural flake; two slight points; 1.1″ by 1.2″ by 0.2″–0″; flaked slightly on rounded edge, small concave cut between the points.

DV:11-142; rhyolite; thick, rough pointed end-and-concave combination, opposite end rounded; 1.7″ by 1.4″ by 0.5″; top edge of point and side very crudely flaked.

Snub-nose Scrapers

DV:11-93; rhyolite; thick, round, top and bottom flat; 1.3″ by 1.3″ by 0.5″; roughly flaked on one edge.

DV:11-105; rhyolite; heavy, crudely flaked tool, narrowing slightly from pointed end to opposite blunt end; 2.4″ by 0.9″ by 0.4″; rudely worked on edge of top surface.

Pointed Scrapers

DV:11-37; rhyolite; natural leaf-shaped flake; 1.8″ by 1.2″ by 0.4″; large flake from concave surface, toward point, and evenly flaked on all edges; heavy patina.

DV:11-38; rhyolite; small flaked tool; slightly concave on under surface; 1.5″ by 1.1″ by 0.3″–0″ on point and sides; flaked sparingly on under surface of one side and top surface of other side.

End Scrapers

DV:11-12; rhyolite; flat, square natural flake; 1.6″ by 1.5″ by 0.4″; rudely flaked around one slightly rounded end.

DV:11-45; rhyolite; thick wedge tapering from natural center line to side edges with slight concavity of lower surface on pointed end; 1.4″ by 1″ by 0.6″; point flaked sparingly.

DV:11-102; chert; white; only tool of this type found; 1.3″ by 7″ by 2″; upper edge of one side, top surface of rounded end, and under surface of opposite end very slightly fashioned; heavy orange patina.

DV:11-122; rhyolite; small, pointed at one end; 1″ by 0.7″ by 3″; natural surface sparingly flaked around end; heavily patinated.

DV:11-145; rhyolite; thick, flat rectangular flake with concave end; 2.1″ by 1.3″ by 0.3″; broad, even flaking on concave edge.

Combination Scrapers

DV:11-16; rhyolite; flat triangular flake; combination end-and-side; 2″ by 2″ by 0.5″; roughly flaked on two edges and pointed end.

DV:11-101; chalcedony; an irregular fragment, natural top surface; 1.7″ by 1.3″ by 0.6″; worked on end and side; extremely heavy patina.

DV:11-106; rhyolite; thin, natural elongated triangle; 2.3″ by 2″ by 0.3″; broadly flaked on side, broad end, and opposite point.

DV:11-112; rhyolite; small, thick, flaked combination end-and-concave side scraper; 1.7″ by 0.9″ by 0.5″; evenly worked on both ends (one pointed); large concave cut on one side.

DV:11-127; rhyolite; irregular flake; 2.2″ by 1.4″ by 0.4″; concave cut and worked point; primary flaking on slightly concave side and opposite end; a well weathered piece.

Scrapers, All Edges Worked

DV:11-25; chert; combination snub-nosed, concave and side; 1.4″ by 1.2″ by 0.4″±; concave-cut, flaked end, sides sparingly flaked; heavily patinated.

DV:11-30; chert; small thin triangular-shaped; 1.1″ by 1″ by 0.2″; worked sparingly on all sides; heavy brown patina on green.

DV:11-32; rhyolite; small flat flake; 1.2″ by 0.8″ by 0.2″; worked on top surface of ends and convex side, opposite side concave.

DV:11-76; jasper; natural triangular flake with high center line; 1.4″ by 1.3″ by 0.8″–0″ on sides and point; slightly worked edges and point.

DV:11-99; chert; half of a round pebble with rounded natural top surface; 2.1″ diameter by 1″–0″ on edge; broad flaking on flattened edge on one side of rounded surface with slight secondary chipping.

DV:11-114; rhyolite; oval flake, top rounded, flat undersurface; 1.6″ by 1.2″ by 0.4″–0″ on edges; flaked slightly on all edges.

DV:11-118; rhyolite; flat, thin, natural flake, slightly pointed end; 1.9″ by 1.4″ by 0.3″–0″; extremely simple flaking.

DV:11-119; rhyolite; small pointed scraper with opposite end concave; 1.2″ by 0.9″ by 0.3″; worked to sharp edge on one side, pointed end possibly broken.

DV:11-125; rhyolite; thick rectangular flake; 2.2″ by 1.8″ by 0.4″; rudely shaped with broad flaking; concave end with corner point.

Keeled Scrapers and Blades

DV:11-2; rhyolite; curved keeled blade with partially natural surface; 3.3″ by 1″ by 0.5″–0″ on edges; sparse uneven flaking on under surface of concave edge and blunt point, convex side carefully worked to sharp edge; a very useful primitive blade.

DV:11-20 (Pl. 2, fig. 8); rhyolite; heavy curved natural rock fragment; 3.9″ by 1.1″ by 0.8″–0″ on one side; evenly flaked on thin edge with small concave section around end and partially down opposite side.

DV:11-130; rhyolite; pointed side scraper, roughly worked; 2.4″ by 1.4″ by 0.5″–0″ on sides; flaked on side edges and point.

Microliths

DV:11-39 (Pl. 3, fig. 10); rhyolite; small simple drill; 1.1″ by 0.6″ by 0.2″; broadly flaked sides with secondary flaking on point; flat under surface and slightly curved top surface.

DV:11-40; rhyolite; pointed scraper from natural fragment; 1.1″ by 0.6″ by 0.2″–0″; minimum of flaking on point and side edges.

DV:11-41 (Pl. 3, fig. 9); rhyolite; tiny pointed scraper which could have been used in a haft; one side natural rounded surface; 0.9″ by 0.5″ by 0.2″–0″; sparse secondary flaking on under edge of point, broad end, and upper edge of one side; heavy patina.

DV:11-42 (P. 2, fig. 7); chert, small weathered side-scraper, cross section triangular, end more recently broken; 1.1″ by 0.8″ by 0.4″–0″; side shows even flaking on upper surface of one edge; heavy dark patina covers green.

DV:11-94; jasper; natural fragment, rounded slightly for use as scraper; 1.1″ by 1″ by 0.3″; one edge worked on both sides, retouched on one; heavy patina.

Gravers and Scraper-gravers

DV:11-33; rhyolite; flat scraper-graver; natural flake with two graver points; 1.6″ by 1″ by 0.2″; all sides worked, points on opposite ends of alternate surfaces.

DV:11-47 (Pl. 2, fig. 6); chalcedony; thumb-nail scraper, one graver point; 1.1″ by 0.6″ by 0.2″; all edges worked on alternate surfaces; white masked by black patina.

DV:11-48 (Pl. 2, fig. 5); chert; an extremely interesting star-shaped, five-pointed graver; natural rounded upper surface, underside natural cleavage surface; 1.3″ by 1.2″ by 0.3″±; five carefully made points with crescents between, which could have been used in smoothing wood or bone; dark green covered by heavy patina.

DV:11-53; jasper; flake-scraper with one graver point; 1.5″ by 0.7″ by 0.3″–0″; long flake, thinned from length of top, side, and end edges; point on opposite end.

DV:11-56; rhyolite; flat flake, convex side-scraper, graver point at corner; 1.5″ by 1.2″ by 0.3″–0″; under surface convex, flaked with slight retouch on upper surface of same edge.

DV:11-58; jasper; handsome keeled-scraper with three graver points; 2.2″ by 1.3″ by 0.9″; under surface flat, natural; top broadly flaked from central keel, lengthwise, to sharp side edges and pointed end; graver points on one side; lack of heavy patina may indicate less antiquity.

DV:11-129; rhyolite; modified snub-nosed scraper with a blunt graver point on either end of a naturally shaped rock; 1.4″ by 1.1″ by 0.6″; both ends crudely flaked.

Drills

DV:11-34; rhyolite; a possible drill; 1.4″ by 0.8″ by 0.4″; worn flaking to shape point barely visible, opposite end evenly flaked to scraping edge; very worn and heavily patinated.

DV:11-137 (Pl. 3, fig. 11); rhyolite; heavy crude drill fashioned from thick flake with flat underside and rounded top surface; 2.1″ by 1.5″ by 0.4″±; primary flaking on alternate edges of drill point (broken), secondary retouch on under edge of convex side.

DV:11-44 (Pl. 3, fig. 12); chert; combination small pointed scraper and drill point; 2.2″ by 0.6″ by 0.3″; thin edges of one side, flattened end and opposite point carefully flaked; green with brown patina; extremely worn.

Blades and Knives

DV:11-4 (Pl. 4, fig. 13); jasper; short-pointed flake knife, possibly for use in haft; 1.5″ by 1.2″ by 0.5″–0″ on sides and point; percussion bulge on one surface, opposite surface shaped by broad flaking from center line to edge of one side, opposite side from center line a natural surface; retouch on alternate edges of sides; dark patina.

DV:11-5 (Pl. 4, fig. 14); chalcedony; knife fashioned from natural form; 1.6″ by 0.7″ by 0.3″–0″; both sides of one edge evenly worked, no other flaking visible; heavy yellow patina on white.

DV:11-7; rhyolite; crude blade with keeled surface, worn; 2.6″ by 1.1″ by 0.4″–0″ at sides and point; scantily flaked edges; heavy patina.

DV:11-51 (Pl. 4, fig. 15); mottled chalcedony; beautifully made flake knife, curved, point missing; 2″ by 1.4″ by 0.4″–0″; underside unworked, top surface shaped by broad flaking; concave side finely flaked on under side, convex side flaked on upper edge augmented by flaking on under edge.

Spear-point

DV:11-100; chalcedony; gray, mottled; fine workmanship, point missing, biface; 3″ by 1.2″ by 0.2″–0″ on sides; excellent craftsmanship, completely fashioned by flaking and retouched edges. The only artifact of this type and fine workmanship found on the site. While patinated, it is definitely of a later culture, and may belong to the people whose fire circle was found on the upper portion of the terrace.

Used Flakes

DV:11-3; rhyolite; leaf-shaped, flat side-scraper; 2.7″ by 1.5″ by 0.3″–0″.

DV:11-72; jasper; flake showing work, and possible use as scraper; 1.5″ by 1.3″ by 0.4″; patinated.

DV:11-80; jasper; 2″ by 0.9″ by 0.3″–0″; heavily patinated.

DV:11-111; rhyolite; pointed side-scraper; 1.6″ by 0.8″ by 0.3″–0″; flaking around side and end faintly visible; very worn and heavily patinated.

Hammerstones, Choppers, etc.

DV:11-85; rhyolite; hammerstone or axe, rudely shaped to chopping edge and point; 3.7″ by 2.6″ by 1.7″–0″.

DV:11-87; chert; pick ?—or core, partially natural surface, shaped to point on one end; in three fragments; 4.2″ by 2.6″ by 1.4″; simple flaking to shape point; heavy brown patina on greenish gray.

DV:11-154; rhyolite; heavy useful chopper; one sharp cutting edge; 4.5″ by 2.6″ by 1.3″–0″; broad, simple flaking on one edge, opposite side of same edge shows slight flaking. From remnant of terrace directly above Manly Terrace.

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CORRELATION OF THE TRIASSIC FORMATIONS OF CANADA

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INTRODUCTION

This is Number 8b of a series of correlation charts of North American sedimentary formations prepared by the Committee on Stratigraphy of the National Research Council with the co-operation of other North American stratigraphers (Dunbar *et al.*, 1942). It is a summary of contemporary knowledge of the stratigraphy and correlation of the Triassic of Canada and is a compilation taken from the literature. A list of the more important papers and reports consulted is appended under References.

It must be admitted that the Canadian Triassic is imperfectly known. In only a few areas have systematic investigations been carried on. Elsewhere stratigraphic studies have not been sufficiently detailed, and the search for fossils has not been intensive enough to yield satisfactory results. In some places investigation is hampered by the scarcity and poor preservation of fossils. It follows that the chart and annotations are actually more a record of unsolved problems than of completed studies, and an appropriate title would be "Problems of the Triassic Stratigraphy of Canada."

ROCKS

A high percentage of the rocks assigned to the Triassic in the Western Cordillera is of volcanic origin. They are mostly of andesitic composition and in places are altered to "greenstones." They comprise both flow and pyroclastic types and occur as lava flows, agglomerates, breccias, and tuffs. Some flows are amygdaloidal, and pillow lavas have been recorded. Dikes and sills occur, as for example in the Vancouver volcanics, where they intrude both the extrusive volcanics and the limestones interbedded with them. They have the same composition as the extrusives, do not invade the overlying formations, and are considered more or less contemporaneous with the extrusives (Clapp, 1912). Rocks of volcanic origin are very meager, or absent, in the Eastern Cordillera—that is, in the Rocky Mountains and Foothills (McLearn, 1940a; Williams, 1947; Hanson *et al.*, 1947).[1]

[1] Allan and Carr (1947) record "bentonite-like clays" in the Triassic of the Highwood-Elbow area, Alberta, and raise the question of whether they are of altered volcanic ash.

Sedimentary rocks, excluding tuffs and sediments of volcanic origin, are mostly fine-grained or calcareous and comprise limestones, calcareous argillites, argillites, phyllites, shales, quartzites, and rare sandstones, calcareous sandstones, and conglomerates. For a long time no "red beds" or evaporites, so characteristic of the Triassic in many parts of the world, were found in Canada. In 1933, however, Allan recorded the discovery of "red beds" and gypsum in the Rocky Mountains, northwest of Jasper.

The relation of the volcanic rocks to the sediments of terrigenous origin is not yet fully understood. The lavas and breccias are interbedded with the sediments. In places, however, the sediments make up a large part of some thick sections and may or may not include tuffs and tuffaceous sediments. They represent times or places, when or where volcanism was much reduced in intensity. Some evidence suggests that the sedimentary or dominantly sedimentary zones are of wide extent. Thus thick sections of sediments, with a minimum of volcanic rocks, of late Upper Triassic age, are found on Graham Island (Mackenzie, 1916), Parson Bay (Crickmay, 1928), vicinity of Kyuquot Inlet (Jeletzky, 1950) and in the southern Yukon (Lees, 1934). It is not known, however, whether a decline in volcanism everywhere marked late Upper Triassic time. At the southeastern end of Vancouver Island volcanic rocks of various kinds are interbedded with Upper Triassic limestone in the Vancouver volcanics, and Mathews (1947) has observed that volcanism continued longer there than in other parts of coastal British Columbia. In the vicinity of Pinchi Lake the Upper Triassic rocks are mostly sedimentary, though whether this is true of all the Fort St. James map area is not known. Armstrong (1946), however, notes that sedimentary rocks are predominant in northern British Columbia in Upper Triassic time. In the Princeton map area Rice (1947) suggests that the thick section of sediments in the vicinity of Hedley may be of the same age as volcanic rocks in other parts of the area. That is, dominantly sedimentary rocks may not there overlie dominantly volcanic zones, as the dominantly sedimentary Parson Bay overlies the dominantly volcanic Valdes beds, and as the dominantly sedimentary Quatsino and Bonanza beds overlie the dominantly volcanic Karmutsen beds in the coastal Islands and on the west coast of Vancouver Island. Although at some stages extrusive activity was intense and widely spread, at other times activity was probably more local, so that, concurrently, lavas, breccias, and other volcanic rocks accumulated at one place, clays and silts at another, and limestones at yet another. If these restricted theaters of volcanism shifted geographically, the relation of the volcanic rocks to the limestones and other sediments would be further complicated. As already noted, some regions were free of volcanic activity throughout all the Triassic.

All authors consider the Triassic beds of western Canada, both volcanic and sedimentary, to be entirely, or almost entirely, of marine origin. The sediments contain marine fossils, many volcanic rocks are interbedded with them, and many lavas have a pillow structure. The few plant remains collected may have been washed into the sea and have come from temporary land areas formed where volcanic products filled in the sea and built up areas above sea level. The red beds and gypsum appear to be marginal deposits on the east shore of the interior Triassic sea, in possibly late Middle or early Upper Triassic time.

Faunal Zones and Correlation

In the Western Cordillera where well-preserved and diagnostic species have been collected and identified they are of Upper Triassic age (Armstrong, 1946). In many, if not in most, areas, however, the few fossils so far discovered merely permit a Triassic dating. Very little faunal zoning has yet been attempted, and the total time range represented by the Triassic terrains has for the most part not been determined. In the Harbledown and neighboring islands, however, the Triassic section ranges at least from Karnian to the late Norian of the Upper Triassic (Crickmay, 1928). The clastic division of the Lewes River group in southern Yukon ranges from about late Karnian to late Norian; and the Nicola group, in the Nicola and neighboring map areas, also ranges from at least late Karnian (Tropitan) to late Norian. At all these localities, however, the total down-

ward range is not known, and it is not established whether any of the sections extend high enough to include strata of Rhaetian or very late Upper Triassic age. The most widely distributed fauna is the late Norian *Monotis subcircularis*, represented usually by the highly diagnostic species for which it is named. In the literature, fossils are listed for the formation or group, as a whole, and little attention is given to faunal zoning within them. As studies become more detailed, however, and the search for fossils becomes more intensive, the possibilities of more refined zoning will doubtless be explored.

In the Eastern Cordillera—that is, east of the Rocky Mountain Trench, in the Rocky Mountains and Foothills—and to some extent on the western border of the Plains, the occurrence of Lower and Middle, as well as Upper, Triassic has been established. The Triassic column has a long time range there, from early Lower Triassic (Otoceratan) to at least late Norian (Pinacoceratan) age of the Upper Triassic. Some offlap to the west, particularly in northeastern British Columbia, is observed, for on the whole the Lower and Middle Triassic extend farther to the east and northeast than does the Upper. This, however, may in part be the result of pre-Jurassic erosion and removal of the higher Triassic along the eastern and northeastern borders. On the whole, more-detailed stratigraphic studies have been made in the Eastern than in the Western Cordillera, and more attention has been given to faunal zoning within the formation. Thus Warren (1945) has recognized at least two faunal zones in the Sulphur Mountain member, Kindle (1944) has found two zones in the Toad formation, and McLearn (1947b) has recorded three faunal zones in the "Gray beds" and at least four in the Pardonet beds.

Unconformities

The relation of the Triassic to the underlying Paleozoic appears in most areas to be that of an erosional unconformity or disconformity. Discordance has been rarely recorded. In some areas the relation is obscure because of poor exposures.

In many parts of both the Eastern and Western Cordillera the relation to the overlying Jurassic is that of a disconformity, or more rarely that of an erosional unconformity. In places the hiatus may not be very great. In one area, however, intrusion, uplift, and erosion of the Triassic is said to have preceded deposition of the Jurassic (Duffell and McTaggart, 1947).

Erosional unconformities have been reported within the Triassic—that is, between one formation or group and another—although rarely. Examples are cited, on a later page, in the Taku map area.

Source of Sediment

A large proportion of the Triassic rocks are of volcanic origin, as already noted. Limestones and fine sediment, now in the form of shale or argillite, indicate deposition far from the source. Some sediments may be reworked volcanic rocks, but a fair proportion, in the form of shales, argillites, sandstones, and quartzites, must have had a terrigenous origin and must have come from the erosion of landmasses above sea level. It is probable that some sediment came from the east, from the site of the present Great Plains. Sediment may also have originated from local uplifts within the Western Cordillera. These uplifts may explain the source of some of the conglomerates.

Paleogeography

The drawing of paleogeographic maps at this stage of our knowledge of the Canadian Triassic is not justified. Throughout nearly all this period long narrow seas must have lain on the site of the present Rocky Mountains and Foothills and on the site of a long, narrow, geosyncline. They were not disturbed by volcanic activity. In parts at least of the Upper Triassic, seas spread widely over the site of the Western Cordillera, and deposits were laid down in one or more geosynclines, much disturbed by volcanism. The great thicknesses of strata, measured in thousands of feet in some areas, bear witness to a geosyncline, or more than one, of great magnitude.

Western Cordillera

Queen Charlotte Islands

1. The lowest known rocks on Graham Island are of Upper Triassic age and outcrop on the

FIGURE 1.—INDEX MAP, TRIASSIC OF WESTERN CANADA
Numbers are those of columns in Plate 1.

northwest shores of the island (MacKenzie, 1916). MacKenzie referred them to his Maude formation. They are said to comprise sediments almost certainly referable to those of the Maude. They are presumably, therefore, thin-bedded, dark argillites and some limestones.

Calcareous argillites occur on Frederick Island. MacKenzie found the late Norian species *Monotis subcircularis* Gabb at Lepas Bay and on Frederick Island. The stratigraphic position of this diagnostic species is, unfortunately, not recorded, and it is not known whether any beds of post-Norian age are represented or whether beds of Karnian age can be inferred. Strata of Norian age probably occur on the shores of Skidegate Channel (Dawson, 1880). MacKenzie probably included the Triassic beds on Graham Island in the Maude formation because of their resemblance lithologically to those of the typical Maude at the type locality of the formation on the southeast coast of Maude Island. They are, however, of a different and earlier age, for the typical Maude is of late Lower Jurassic or Toarcian time (McLearn, 1949). The questions are: Do these Upper Triassic beds pass up into the Jurassic argillites without change? Is there an intercalation between them of beds of volcanic origin or is there a break in the succession? If they are similar lithologically to those of the Maude and pass up into them without change, MacKenzie's inclusion of both the Triassic and Jurassic beds in one formation or group seems justified.

2. Triassic strata probably underlie large areas on Moresby Island and on the smaller islands off its northeastern and southern coasts. No important studies have been made since those of Dawson (1880). Argillites and limestones are recorded and are said to overlie greenstones, but the relation of the sedimentary to the volcanic rocks is not definitely stated by Dawson, and our knowledge of the stratigraphy of the southeastern part of the Queen Charlotte Islands is very limited. The late Norian species, *Monotis subcircularis* Gabb, is recorded by Dawson (1880) from argillites overlying limestone on the south arm of Cumshewa Inlet; from argillites on a small island near the entrance to Echo Harbour; from limestone near the base of a thick section of argillites and limestones at Section Cove, on the north side of Burnaby Island; and from a succession of argillites and limestones on Houston Stewart Channel. The age is partly Norian and Upper Triassic, but the occurrence of the late Norian species, *Monotis subcircularis* Gabb, deep down in a thick section of argillites and limestones, as at Section Cove, raises a question of whether some of the beds are of post-Norian and perhaps even of Jurassic age.

Vancouver Island

Although Selwyn had used the name Vancouver informally in 1872, in reference to the "Vancouver Island Coal Rocks" and the "Vancouver Island Limestone", it was not until 1887 that a stratigraphic unit bearing this name was definitely recognized and defined. In 1887 Dawson proposed that the pre-Cretaceous, dominantly volcanic beds of Vancouver Island be called the Vancouver series. This he stated consists mostly of volcanic flows, tuffs, and breccias and, to a lesser degree, of interbedded limestone, flaggy argillite and quartzite. He was able to establish the Triassic age of some of this series and proposed that if it were found that Carboniferous beds existed on the island, the name Vancouver be reserved for the Triassic part. What appear to be Paleozoic formations have been discovered, and the name, in later years, has been used as a group name to comprise not only Triassic but Jurassic and probably even some Lower Cretaceous beds as well; that is, the pre-batholithic Mesozoic strata of Vancouver Island. As the study of the Mesozoic stratigraphy of this island progresses, however, a tendency is noted to dispense with this group and replace it with stratigraphic units of shorter time range.

Rocks of Triassic age doubtless underlie very large areas on Vancouver Island. In only a few areas, however, have they been identified by diagnostic fossils.

3. On Quatsino Sound, near the northwestern end of Vancouver Island, Dolmage (1919) has described a great thickness of andesites and tuffs, interbedded with lesser amounts of limestone, in places argillaceous. One thick bed of limestone, near the middle of the section, has been separated by him and named the Quatsino formation.

4. In the Nimpkish Lake area Gunning (1932) has given the name Karmutsen group to the oldest rocks in the area, basaltic and andesitic flows, breccias, tuffs, and lesser amounts of limestone. This group is well exposed in the Karmutsen Range, west of Nimp-

kish Lake and presumably the type locality. He correlates the overlying and conformable white to gray, crystalline limestone with the Quatsino formation of Quatsino Sound, but advises that if this correlation is incorrect the name Nimpkish be given to this limestone formation in the Nimpkish area. He proposes the name Bonanza group for the overlying beds. It consists of a lower largely sedimentary division comprising tuffs, dark limestones, argillites, quartzites, and minor proportions of interbedded flows and an upper division, comprising mostly flows and tuffs. Gunning records *Monotis subcircularis* from the lower and dominantly sedimentary part of the Bonanza group. A similar succession was found by Gunning (1933) in the Zeballos River area and by Hoadley (1950) in the coastal part of the Zeballos area. The lower part of the Bonanza group is of Upper Triassic, and the upper part probably of Jurassic age (Gunning, 1930; Hoadley, 1950). The Quatsino and the Karmutsen are included in the upper Triassic (*See* below).

5. The Triassic succession in the coastal area between Kyuquot Sound and Esperanza Inlet is not yet completely established (Jeletzky, 1950, and oral communication). The lowest beds observed comprise pyroclastic rocks and flows, with limestone lenses carrying Karnian fossils at the top and probably comparable with the Karmutsen volcanics of the Nimpkish Lake area. They grade up into bedded impure limestone with fossils of Karnian age, probably equivalent to the Quatsino limestone. Higher are beds of the sedimentary part of the Bonanza group, the details of which are as yet unknown. In faulted contact with the Quatsino limestone on the west side of Union Island are thin-bedded shales, limestones, and quartzites carrying, in ascending order, *Halobia*, *Distichites*, and *Monotis subcircularis* faunas, the last two of which are definitely of Norian age. A somewhat different section is found by Jeletzky at Brecciated Point (Jeletzky, 1950, map). There shales with *M. subcircularis* are in contact with arenaceous beds which in turn are in contact with limestone. It is not known, however, whether the arenaceous beds underlie or overlie those with *M. subcircularis*. It is therefore difficult to determine the relation of the arenaceous beds to those in the section on Union Island, whether they belong to the upper part and have been removed by erosion or whether they occur lower and have been faulted out between the beds containing *Halobia* and the Quatsino limestone (J. A. Jeletzky, oral communication). The section on the chart is drawn in accordance with the second hypothesis, but further work will be necessary to establish precisely the position of these beds.

Near Mushroom Point, volcanic rocks believed by Jeletzky (1950) to be of Jurassic age rest on the uneven and deeply eroded surface of the *M. subcircularis* shales. Jeletzky suggests that the unconformity probably does not mark the Triassic-Jurassic boundary, but is above it, and that some early Lower Jurassic beds may have accumulated prior to the uplift and erosion recorded by the erosional unconformity.

6. In the Buttle Lake area, west and northwest of Comox, the Permian is overlain, probably disconformably, by pillow lavas, breccias, and other volcanic rocks. Above them are impure, dark-gray limestone and argillite, carrying Triassic fossils, on the upper reaches of Iron River. Fossils are not sufficiently diagnostic to indicate the stage represented within the Triassic (Gunning, 1931).

7. In the southeastern part of Vancouver Island the Nitinat formation, the Vancouver volcanics, and Sicker group have been placed in the Vancouver group. Clapp (1912, 1917) considers that this group is underlain unconformably by the Leech River formation and Malahat volcanic rocks, assigned by him to the Paleozoic. Mathews (1947), however, believes that the age of the Nitinat, Leech River, and Malahat is uncertain. The Vancouver volcanics first recognized by Clapp in 1910, underlie large areas in the southeastern part of Vancouver Island and consist of interbedded and conformable flows, breccias, slaty and cherty tuffs, mostly of andesitic composition, and lenses of limestone. Some sills and dikes of andesitic and basalt porphyry show intrusive contacts with the limestone and other bedded rocks. The intercalated limestone beds are found at all horizons. About 400 feet of limestone near the middle of the Vancouver volcanics has been called the Sutton member by Clapp and Shimer (1911). The type locality is on the south shore of Cowichan Lake, about 3 miles northwest of

the mouth of Sutton Creek. The fauna of the Sutton has been described by Clapp and Shimer (1911) and includes *Choristoceras* sp., *Myophoria suttonensis* Clapp and Shimer, *Terebratula suttonensis* Clapp and Shimer, and corals. It is not earlier than Norian and may be of part or all of that time. The exact age of the upper and unfossiliferous part, which is above the Sutton member, is unknown, but is tentatively considered Triassic.

The Sicker group, first described as the Mount Sicker by Clapp (1909), comprises unfossiliferous volcanic and sedimentary beds (Clapp, 1912; Cooke, 1917). They have been considered to be probably conformable with and altogether younger than, or partly equivalent to, the Vancouver volcanics (Cooke, 1917). Mathews (1947), however, notes the resemblance of the Sicker to beds of Paleozoic age southeast of Alberni.

Islands between Queen Charlotte Strait and Strait of Georgia

8. A good Triassic section is exposed on Swanson, Harbledown, and Hanson islands and has been described by J. A. Bancroft (1913) and Crickmay (1928). The lowest formation is the Valdes which comprises lavas, agglomerates, and tuffs and very rare limestone and argillite. Near the top Crickmay collected corals, referred by him to *Isastraea vancouverensis* Clapp and Shimer.

The overlying Parson Bay formation was originally described by J. A. Bancroft (1913) and was said to contain carbonaceous shale, argillite, impure limestone, calcareous sandstones, quartzites, and very rare volcanic rocks. Crickmay (1928) divided the group into two formations—a lower one, of Triassic age, for which he retained the name Parson Bay, and an upper one, of Jurassic age, for which he proposed the name Harbledown formation. The lowest exposed beds of the Parson Bay are said to contain *Juvavites? knowltoni* Smith and *Halobia alaskana* Smith of Karnian and possibly late Karnian age. About 600 feet higher *Halobia* cf. *cordillerana* Smith is recorded. About 250 feet above this Crickmay collected *Monotis alaskana* Smith of about mid-Norian age. Approximately 200 feet higher, the late Norian species *Monotis subcircularis* Gabb occurs. Yet higher, and about 400 feet above the *M. subcircularis* beds, the noncalcareous argillites and thin beds of green, cherty quartzites of the Harbledown formation appear. Ammonoids of Lower Jurassic age are found 200 feet above the base of this formation. Crickmay infers that the contact between the two formations is disconformable. The exact age of the uppermost 400 feet of the Parson Bay and of the basal 200 feet of the Harbledown, however, is not known. The uppermost part of the Parson Bay, for example, may be very late Norian or Rhaetian—that is very late Upper Triassic—, or it may even be very early Jurassic.

As Crickmay has noted, volcanism was at a minimum in later Upper Triassic and in early Jurassic time in this part of British Columbia.

9. The section exposed at Open Bay on Quadra or South Valdes Island was studied by J. A. Bancroft (1913). He concluded that the limestones, exposed in the northeast part of the bay and to the northwest across the island, lie at the base of the local succession. Because he considered them lithologically similar he correlated them with the limestones of the Marble Bay formation on Texada Island. He also described the occurrence of argillites or thinly bedded (ribboned) quartzites and cherts with sills of augite andesite and diabase in the middle of the bay, inferred that they conformably overlay the "Marble Bay" limestones, and proposed that they be united in a new formation to which he gave the name of Open Bay. He furthermore inferred that the andesitic, partly amygdaloidal lavas, agglomerates, tuffs, and rare limestones, which outcrop on the southwest part of the bay, overlay the "Open Bay" beds and he named them Valdes formation. Bancroft obtained no fossils, so that his interpretation of the succession could not be tested.

Gunning later studied this section, and his results have been recorded by Matthews (1947). He differs fundamentally from Bancroft and believes that the succession as interpreted by him must be inverted and that the volcanic beds called Valdes by Bancroft lay at the base, not at the top of the Open Bay succession. Gunning's description of this succession, as recorded by Mathews, differs materially from

that of Bancroft. He describes no unit of argillites or thinly banded quartzites, with sills of igneous rocks, that can be separated from the remaining part of the succession, as an Open Bay formation. Rather the succession, as observed by Gunning, is one of alternating thick zones of argillaceous limestones and volcanic rocks, and they include not only the beds in the middle part but in the northeastern part of the bay as well. That is, they comprise the beds mapped both as Open Bay and as Marble Bay by Bancroft. Gunning's section, as recorded by Mathews (1947), is as follows:

	Feet
Intensely folded argillaceous limestones and pillow lavas	(top)
Argillaceous limestone with a greenstone band	500±
Lava	200
Argillaceous limestone	50
Ellipsoidal and massive lava	350
Argillaceous limestone (base)	100
Valdes volcanic rocks	(bottom)

He collected fossils of Karnian age on the western edge of the intensely folded belt. Presumably Bancroft's argillites are the argillaceous limestones and his sills are the lava beds of Gunning. It does not seem desirable to divide this section into two formations, an Open Bay and a "Marble Bay." Nor does it appear advisable to consider it an upward extension of the Valdes (or Texada), for the limestones are very much thicker than any of the mere lenses of limestones in either the typical Valdes or typical Texada.

No part of the exposed section on Hanson and Harbledown islands corresponds to this unit of interbedded, massive, argillaceous limestones and volcanic flows. Crickmay (1928), however, claims that about 600 feet of strata is concealed between the highest exposures of the Valdes on Hanson Island and the lowest exposures of the Parson Bay on Harbledown Island. Bancroft's name of Valdes is retained for the volcanic rocks on the southwest side of the bay, which is indeed part of the type area of this formation.

10. The Anderson Bay, the oldest formation on Texada Island, consists of mixed volcanic and clastic rocks and some limestone. It is much more metamorphosed than the other formations on the island. A few fossils, including large crinoid stems, have been found, and it has been tentatively dated both Paleozoic and Triassic (McConnell, 1910; 1914a). It is probably Paleozoic (Mathews, 1947).

The Texada group overlies the Anderson Bay formation with a slight angular unconformity (Mathews, 1947). It was first described by LeRoy (1908) as massive pyroclastic basic rocks and flows with some well-bedded tuffs, slates, cherts, and limestones. As used by LeRoy this group comprises not only deposits on Texada Island, but deposits at some other localities in the Straight of Georgia area as well. He obtained no fossils but assumed a Devono-Carboniferous age and inferred that they are older than the Marble Bay formation. McConnell (1914a) took quite a different view of the Texada group. He stressed the massiveness of the rocks. Although admitting that a small part could be of effusive origin and that some limestone is present, he considered the Texada mainly an intrusive body, particularly in its relation to the Marble Bay and Anderson Bay formations. He noted, however, that the amygdaloidal, and what he called nodular, structures indicate cooling under a low overburden. He inferred that the Texada is of about the time of the Vancouver volcanics of Vancouver Island, but later than the Marble Bay formation and of about Lower Jurassic age. Mathews (1947) has reverted to LeRoy's idea that the Texada is older than the Marble Bay and describes it as a formation of chiefly massive, amygdaloidal, and pillow lavas, together with possibly some agglomerate, greenstones of uncertain origin, and limestone lenses. Fossils collected by Mathews 1½ miles northwest of Davies Bay on Texada Island include ammonoids of Karnian (Upper Triassic) age.

The Marble Bay formation on Texada Island has been described by LeRoy (1908), McConnell (1910; 1914a), and Mathews (1947) and consists of pure limestone and dolomitic limestone. It apparently rests conformably on the Texada group. The change from volcanic rock to limestone, however, is mostly abrupt, although interbedding of limestone and volcanic beds has been observed near the contact (Mathews, 1947). The formation is divided into three members by Mathews: the lowest consists almost entirely of high-

calcium limestone; the middle member contains predominantly calcium limestone, but includes also some magnesium limestone; and the highest member is mostly magnesium limestone. Mathews notes that the contacts between the members are not everywhere at the same horizon. It has been dated Paleozoic (LeRoy, 1908; McConnell, 1910) and tentatively Triassic or Jurassic (McConnell, 1914a). Fossils collected by Mathews are probably of Triassic age. The Marble Bay is, furthermore, conformable with the underlying definitely Triassic Texada. It is therefore included in the Triassic. The now greatly restricted Cretaceous beds, on the island, overlie the Texada unconformably. Were the contacts with the Marble Bay preserved, the relation would likely be the same. All Cretaceous beds, however, have been eroded from the top of the Marble Bay formation.

The Texada group is in part at least younger than the Valdes of Quadra Island. At least its upper limit is at a higher horizon, unless the Valdes at Open Bay is extended high enough to include the argillaceous limestones and volcanic rocks of Open Bay, for both the Texada and these Open Bay beds contain a Karnian fauna. With our present knowledge, therefore, some caution must be exercised in attempting to correlate the limestones of the Marble Bay formation with the limestones of Open Bay. The Marble Bay may be partly of later date. If contemporaneous, however, the limestones must become less argillaceous and finally almost free of insoluble matter between Quadra and Texada islands, and the volcanic rocks interbedded with the thick limestones at Open Bay must vanish in the same direction. Insofar as known no beds equivalent to the upper and greater part of the Parson Bay formation occur on either Quadra Island or Texada Island.

Yukon

11. Although the Triassic probably underlies large areas in the central Yukon, fossil evidence has established it at only one locality. In 1906 Keele recorded Triassic fossils in dark limestone, interbedded with argillite on Beaver River, a tributary of the Stewart, near the mouth of Rackla River. A restudy of Keele's collections shows that it includes *Monotis subcircularis* Gabb and *Monotis alaskana* Smith. The two species are on separate specimens, and the *M. subcircularis* is probably from a slightly higher horizon than *M. alaskana*. One is about mid-Norian, and the other late Norian or late Upper Triassic.

Specimens of *Monotis subcircularis* have been collected by McConnell (1906) from dark shales near the center of the lower canyon of Burwash Creek, in southwestern Yukon.

12. In 1934 Lees gave the name Lewes River to the Triassic limestones and clastics of the Laberge area in the southern Yukon. A list of fossils from a clastics division includes the late Karnian species *Halobia ornatissima* Smith and *Juvavites subinterruptus* Mojsisovics and the late Norian species *Monotis subcircularis* Gabb, thus recording a long range of time within the Upper Triassic (Cockfield and Lees, 1931; Lees, 1934). Limestone said to contain *Dielasma julicum* Bittner on Lewes Mountain is probably of Karnian and Upper Triassic age (Cockfield and Lees, 1931). The stratigraphy of the Triassic of the Yukon is not yet fully established.

The Lewes River group may be underlain disconformably by the Permian Braeburn formation, but the nature of the contact is not definitely known. In the Teslin-Quiet Lake area Lees (1936) infers that the overlying Jurassic Laberge group rests on the Lewes River with an angular unconformity. In many parts of southern Yukon, however, the relation is probably that of a disconformity.

Northern British Columbia

13. In the northeast part of the Taku River area, in the Coast Mountains of northeastern British Columbia, Kerr (1945; 1948a) has recognized three stratigraphic units in the Triassic. The King Salmon group is presumed to overlie the Permian limestone unconformably and comprises, below, mostly banded, volcanic rocks, lavas, tuffs, and breccias and minor amounts of argillites and quartzites and, above, dominantly argillites and quartzites. The Stuhini group overlies the King Salmon with an erosional unconformity and comprises much volcanic material, including massive andesitic lavas in the lower part. Above this,

with some evidence of an erosional unconformity, are well-bedded graywacke and breccia and some interbedded tuff, limestone, and conglomerate. The Honakta formation, mostly limestone, is said to overlie the Stuhini group with an erosional unconformity. Fossils are not listed, but are said to indicate a Triassic age for all the three groups. The Jurassic Takwahoni group probably overlies the Triassic with an erosional unconformity (Kerr, 1948a).

No Triassic has been definitely identified in the Tuya-Teslin area, but the age of the Nazcha formation has not been established (Watson and Mathews, 1944).

14. Triassic limestone has been recorded by Kerr (1926) in the Dease Lake and Eagle-McDame areas, on the Tanzilla Plateau and in the Stikine Ranges. He proposed the name Thibert for a group which was said to consist of a thick bed of serpentine overlain by limestone. Near the head of Dease River, where it flows out of Dease Lake, Kerr collected *Isastraea vancouverensis* Clapp and Shimer and other corals. The Thibert was said to overlie the Permian Dease group unconformably and to be overlain, probably unconformably, by the Jurassic McLeod group. Hanson and McNaughton (1936) do not accept the serpentine as an altered flow or tuff, but consider it an altered basic intrusive. They reject the existence of a Thibert group and propose that the fossiliferous limestone found by Kerr is an upper part of a long-ranging Dease group.

15. In the Lower Stikine River area, in the Coast Mountains, southwest of the Dease Lake area, Kerr (1948b) recognizes within the Triassic a lower or Volcanic group and an upper or Sedimentary group. The Volcanic group overlies the Paleozoic with an erosional unconformity, resting in places on the Permian and elsewhere on the pre-Permian. It consists below mostly of massive pyroclastic rocks and rare lavas and above of conglomerate, limestone lenses, tuffs, and agglomerates. The Sedimentary group occurs mostly in the northern part of the area and overlies the Volcanic group with some evidence of an erosional unconformity. It comprises dark, partly calcareous argillites and some lenses or beds of dark limestone, conglomerate, sandstone, and dacite tuff. The Sedimentary group is overlain, with an erosional unconformity, by beds of Lower Jurassic age.

The Volcanic group carries poorly preserved fossils of probable Triassic age. The Sedimentary group contains *Monotis subcircularis* and other fossils and is of Upper Triassic, possibly late Karnian to late Norian age.

16. The Takla group was proposed by Armstrong (1945) for a thick succession of volcanic and sedimentary rocks of Triassic and Jurassic age, in the Takla area, which is the northwest quarter of the Fort St. James map area. The name has since been extended to embrace similar rocks of similar age over all the Fort St. James, McConnell Creek, and Aiken Lake map areas, in the Omineca Mountains and Nechako Plateau. The type area is that around Takla Lake.

In the McConnell Creek area, the beds of the Takla group are said to rest on the older and Permian rocks with an erosional unconformity (Lord, 1948). In the Aiken Lake area, the Takla is said to be structurally conformable with beds of late Paleozoic age, but the contact is presumably that of an erosional unconformity (Roots, 1948). The same relation to the older rocks is said to obtain in the Manson Creek map area, in the northeastern quarter of the Fort St. James area (Armstrong and Thurber, 1945). In parts of the Fort St. James area, however, Armstrong (1949) cites evidence to prove that the late Paleozoic Cache Creek group was invaded by the Trembleur ultrabasic rocks and that uplift, erosion, and even some deformation followed, prior to the deposition of the Takla sediments.

Armstrong (1949) states that the Takla group comprises an apparently conformable succession of interbedded volcanic and sedimentary beds. He notes that the succession has been established only in a general way because of the great thick masses of volcanic flows and the few fossiliferous beds. Not much, therefore, can be said of the distribution of volcanic and sedimentary rocks either vertically or laterally. He makes the broad statement that sediments, including limestones and tuffs, are more common in the lower part, of Triassic age, and that flows are more common in the upper part, of Jurassic age. Argillites, graywacke, and tuff, with some beds of conglomerate and brownish

limestones, are common in the vicinity of Pinchi Lake, and two thick lenses of limestones, 150 and 300 feet thick, occur near the east end of the lake. Undivided Takla strata and volcanics, including andesitic and basaltic flows, breccias, agglomerates, interbedded with shale, graywacke, conglomerate, and limestone, underlie large areas. Over most of these areas the Triassic and Jurassic parts of the Takla group appear to be conformable, at least structurally conformable. In the Aiken Lake map area, however, Armstrong (1946) states that a conglomerate, several thousand feet thick, near the middle of the Takla group, indicates an interval of uplift, intrusion, and erosion.

Triassic fossils, some indicating definitely an Upper Triassic age, are found in places. Armstrong and Thurber (1945) report the Upper Triassic genus *Halobia* in argillite south of Chuchi Lake. Armstrong (1949) records the late Norian species, *Monotis subcircularis* Gabb, in limestone on the north shore of Pinchi Lake and *Halobia* sp. on Halobia Creek, about 3 miles above its mouth. It is not known whether any Rhaetic is represented in this group. No fossil record of it has been found.

The age of the Bitter Creek formation (McConnell, 1911) in the Portland Canal and Alice Arm areas is uncertain. Its dark argillites, rare limestones, and tuffs are, insofar as known, unfossiliferous. It has been placed tentatively in the Jurassic or even Triassic by Hanson (1929; 1935) who suggests that the formation name be discarded and the beds included in the lower sedimentary division of the Hazelton group. As the age is uncertain it is not included in the Triassic chart.

The Kitsalas formation, east of the Coast Range batholith, on Skeena River consists of volcanic and sedimentary beds. It is unfossiliferous but has been tentatively dated Triassic by McConnell (1914b). Hanson (1929), however, suggests a Jurassic age.

The Prince Rupert formation, on the west flank of the Coast Range batholith, in the vicinity of Prince Rupert has been tentatively placed in the upper Paleozoic by McConnell (1914b) and in the Triassic or Carboniferous by Dolmage (1923) and Hanson (1925). No fossils have been found, and its exact age is uncertain.

17. Hanson (1926) describes an unnamed group or formation on Zymoetz River and Kleanza Creek, on the eastern border of the Coast Range. It comprises crystalline limestone, cherty quartzite, slate, and argillite with some conglomerate, breccia, and tuff. Limestone boulders in a conglomerate carry fossils of Permian age. An argillite bed contains *Halobia* (or *Daonella*). This sedimentary unit is considered by Hanson to be older than the Hazelton group, although no contact has been observed.

Southern British Columbia

18. Interbedded argillaceous sediments, breccias, and tuffs in the Whitesail Lake and Nechako areas have been referred to the Triassic by S. Duffell and H. W. Tipper (personal communication). They are of, or are equivalent to, the Takla group of the Fort St. James and adjoining areas.

Probably many of the pre-batholithic rocks along the Pacific coast and on the coastal islands and along the numerous inlets, from Prince Rupert to Queen Charlotte Sound, are of Triassic age. They have so far, however, proved to be unfossiliferous.

19. A thick succession of volcanic rocks, interbedded with argillite and lenses of limestone, outcrops on a mountain northwest of the West Homathko Valley, on the eastern edge of the Coast Range, west of Tatlayoko Lake. Fossils include *Isastraea*, *Daonella* (or *Halobia*?), and *Pecten* and are of Triassic age. Similar rocks, but from which no fossils have been collected, outcrop on Klinaklini River and Mount Kappan and in an area north and northwest of Hotnarko and Bella Coola rivers (Dolmage, 1926).

20. A large area in the vicinity of Chilko and Taseko Lakes is underlain by andesitic and basaltic lava flows, and andesitic and rhyolitic tuffs, with lesser amounts of argillite, sandstone, and conglomerate and rare limestone. Argillites carry the Triassic genus *Halobia* (or *Daonella*?). These rocks are intruded by the Coast Range batholith (Dolmage, 1925).

In the Britannia area on the west side of the

Coast Range, the pre-batholithic rocks are incorporated in the Britannia group, first named by LeRoy (1908), which embraces the Britannia and Goat Mountain formations. The Britannia formation comprises mostly clastic sediments, but includes also some tuffs and flows. The Goat Mountain formation contains a high percentage of volcanic rocks. The entire group has been compared with the Vancouver group of Vancouver Island (James, 1929). As no fossils have been found, however, the age cannot be determined. This group therefore has not been included in the Triassic chart.

21. In the Bridge River district, on the eastern flank of the Coast Range, in southern British Columbia, the Noel and Pioneer formations and the Hurley and Tyaughton groups are of Triassic age (Cairnes, 1937; 1943). The lowest unit, the Noel formation, is said to be structurally conformable with the underlying, late Paleozoic Ferguson group, but the contact may be disconformable. The Noel consists of unfossiliferous, banded, argillaceous and tuffaceous sediments with rare volcanic rocks (Cairnes, 1937; 1943). The overlying, partly conformable and partly intrusive, Pioneer formation is unfossiliferous and comprises andesitic lavas, agglomerates, tuffs, and some massive, greenstone-diorite bodies (Cairnes, 1937; 1943). The succeeding and apparently conformable beds of the Hurley group are mostly sedimentary like those of the Noel, but they are more calcareous. They comprise argillaceous and tuffaceous, cherty beds, some limestone and conglomerate, and some layers of volcanic rocks. A few fossils, including corals, have been found in the Hurley and indicate a Triassic, probably Upper Triassic age (Cairnes, 1943). The names Noel, Pioneer, and Hurley were all proposed and first used by Cairnes in 1937 and applied to beds in the Bridge River district.

Joubin (1948) offers a somewhat different interpretation of the succession, which he considers to be, in ascending order, the Pioneer rhyolites and greenstones, Hurley-Noel conglomerate, and the Hurley-Noel sediments.

The Tyaughton group was erected in 1943 for beds high in Triassic in the Tyaughton map area (Cairnes, 1943). It is recognized only in this northern part of the Bridge River district. The only contacts with the Hurley are fault contacts. It comprises interbedded sandstone, shale, grit, conglomerate, and thick beds of limestone. The fossils, collected by Dolmage, Crickmay, and Cairnes, include *Monotis subcircularis* (Gabb), a variety or subspecies of *Cassianella beyrichi* Bittner and several very ornate species of *Myophoria* (Cairnes, 1943; McLearn, 1942). The *Monotis* is of late Norian age. The stratigraphic relations of the several faunas have not been established, but cephalopods associated with *Cassianella*, which include *Rhabdoceras* cf. *suessi* Hauer, also suggest a Norian age. Some resemblance in the species of *Myophoria* is shown to the fauna of the Sutton member of Cowichan Lake. It is not now known how high in the Triassic the Tyaughton beds extend. Although the Tyaughton is mostly in faulted relation with the Lower Jurassic beds, Cairnes (1943) suggests a conformable contact.

Drysdale (1916) proposed the name Cadwallader for a thick succession of sedimentary rocks together with some volcanic rocks, including greenstone and andesite lavas. He also gave the name Shulaps volcanics to some basic rocks altered to serpentine. Later McCann (1922) placed the Cadwallader definitely in the Triassic, having found a coral fauna in it on Pearson Creek. This fauna was studied by Shimer (1926) who considered it to be of Norian age. Drysdale placed the Shulaps below the Cadwallader, but retained it in the Triassic. The Cadwallader corresponds in a general way to the Noel, Pioneer, and Hurley units. The Shulaps comprises rocks now considered to be intrusive (Leech, 1949), and it no longer has the status of a formation.

Crickmay (1930a) has proposed the name Slollicum for a series of rocks comprising schists, argillites, and greenstones on the east side of Harrison Lake, on Mount Cheam and Vedder Mountain. The age is said to be Triassic. No fossils, however, are cited.

22. The Cultus formation (Daly, 1912) on the east side of Cultus Lake, is said to comprise dark argillite, some sandstone and grit, and rare, fine conglomerate. The fossils recorded by Daly, *Aulococeras* sp., said to be similar to *A. carlottense* Whiteaves, and *Arniotites vancouverensis* Whiteaves, if cor-

rectly identified, suggest late Upper Triassic and Lower Jurassic respectively. Crickmay believes that the beds called Cultus by Daly do not represent a continuous succession, but a series of "slices" or schuppen of Carboniferous and Lower Cretaceous rocks in a fault zone.

23. The Nicola group underlies large areas in southeastern British Columbia, in the Ashcroft, Nicola, Hope, and Princeton map areas, between 120° and 122° Long. and between 49° and 51° Lat. It was first named and described by Dawson (1879), and the type area is in the vicinity of Nicola Lake, in the southern part of the Nicola map area.

In the Nicola area, the Nicola group lies on the Cache Creek group, predominantly of Permian age, with an erosional unconformity, in the sense that some of the older rocks were eroded before deposition of the Nicola; and with a disconformity, in the sense that probably no deposition took place in late Permian and early Triassic time (Cockfield, 1948). The same appears to be true of the Ashcroft area (Duffell and McTaggart, 1947). In the Princeton area the Nicola group is not anywhere in direct contact with any of the older rocks, for the Paleozoic Hozameen group occurs only in the southwesternmost corner of the area.

The Nicola group consists mostly of volcanic rocks with lesser amounts of sedimentary rocks, argillites, limestone, and rare conglomerate in the Nicola map area (Cockfield, 1948). The volcanic rocks are chiefly greenstones, andesitic and near-basaltic lavas, breccias, tuffs, and agglomerates. Little stratigraphic information concerning the group itself is given. Cockfield notes that tuffs are apparently more common in the upper part of the section. He also notes that the late Norian species, *Monotis subcircularis* Gabb, occurs in the matrix of a conglomerate interbedded with limestone near Stump Lake. No mention is made of the stratigraphic level of this conglomerate within the group. Unless the Nicola extends high enough to include beds of Rhaetian (latest Upper Triassic) or Jurassic age, then surely the conglomerate and associated limestone are the highest beds in the Nicola group. In the Ashcroft area this group contains rocks similar to those in the Nicola area. The beds at one level can be accurately dated, for in a limestone interbedded with volcanic and sedimentary layers, near Basque, a late Karnian fauna with *Tropites* has been found (Crickmay, 1930b; Duffell and McTaggart, 1947). These beds are older than the conglomerate at Stump Lake, but the exact level at which they occur in the Nicola group has not been recorded. Combining our fossil evidence from the Nicola and Ashcroft areas, it can be assumed that the Nicola group is at least of Upper Karnian to late Norian age.

24. For the Princeton map area, Rice (1947) suggests lateral variation in the Nicola group. Some sections contain more volcanic materials than others. Rice notes that the Nicola group mostly consists of volcanic rocks, together with minor proportions of argillite, limestone, and rare conglomerate. In some parts of the area, the group comprises sedimentary rocks almost entirely. This is true of the area near Hedley (Rice, 1947). A special classification has been proposed for this area, and it has been revised several times. Camsell (1910) erected the following formations, in ascending order: Redtop, with the Stevenson limestone member at the base; Nickel Plate, with the Sunnyside limestone member near the base and the Kingston limestone member at the top; Red Mountain; and Aberdeen. In 1930, Bostock adopted this classification, but added an unnamed formation at the top and also proposed some new members. He divided the Nickel Plate formation, in ascending order, into the Sunnyside limestone, Sunnyside productive beds, Lower Siliceous beds, and Nickel Plate productive beds. He divided the Redtop formation into the Upper Siliceous beds, Summit beds, and Red Mountain in the strict sense. In 1940 Bostock made a further revision, proposing in ascending order, the Redtop, Sunnyside, Hedley, Henry, and Wolfe Creek formations. The Hedley, a new formation, comprises the old Nickel Plate formation, with the exception of the Sunnyside limestone, and all of the original Red Mountain formation. The Henry is a new formation, and the Wolfe Creek had previously been described in the neighboring Copper Mountain area (Dolmage, 1934). The Redtop is a strikingly banded formation and consists of siliceous and argillaceous beds, limestones,

and volcanic rocks. The Sunnyside is a limestone. The Hedley comprises limestones, banded quartzites, and some breccias and tuffs. The Henry consists of black argillite, tuff, and impure limestone. The Wolfe Creek comprises mostly volcanic rocks (Rice, 1947).

Some fossils have been collected from various horizons and facies, including *Halobia*, and *Discotropites?* sp. They are mostly not very diagnostic, but do indicate a Triassic and probably an Upper Triassic age (Rice, 1947).

Very little is known of the contact of the Nicola group with later rocks, in the Nicola area. It is intruded by plutonic rocks of probable late Jurassic age and overlain unconformably by beds of possibly later Mesozoic or even Tertiary age. The relation to later beds is also obscure in the Princeton area, where the Nicola group is intruded by the late Jurassic batholiths and at one locality is overlain unconformably by the Lower Cretaceous Pasayten formation (Rice, 1947). In the Ashcroft map area Duffell and McTaggart (1947) state that beds of the Nicola group are overlain unconformably by sediments of Jurassic age, near Ashcroft. The same Jurassic sediments are said to overlie unconformably granitic rocks which are intrusive into the Nicola group.

On the south Thompson River, in the vicinity of Ducks, and west of Shuswap Lake, massive, altered basaltic and andesitic lava flows with interbedded breccias and tuffs rest with an erosional unconformity on beds probably of Carboniferous age. These rocks are unfossiliferous but have been tentatively correlated with the Nicola group by Daly (1915). They have also been described by Rice and Jones (1948).

The Tulameen group was proposed by Camsell (1913) for a succession, predominantly of volcanic rocks, but with minor amounts of clastic sediments in the Tulameen map area, a western part of the Princeton map area. Camsell noted the resemblance of these beds to those of the Nicola group in the Nicola area. He collected some plant remains, identified as *Baiera* by Knowlton. Rice (1947), who has studied the whole Princeton area, which, as already noted, includes the Tulameen area, treats Tulameen as a synonym of Nicola.

The age of the Bradshaw, Independence, Shoemaker, and Old Tom formations, named by Bostock (1940) in the Similkameen Valley, south of Hedley, is uncertain but may be Mesozoic.

25. In the Slocan and Sandon map areas, between Slocan and Kootenay lakes, the upper part of the Milford and all of the Kaslo and Slocan groups have been referred to the Triassic. The Milford group, first named by Bancroft (1920) and revised by Cairnes (1934), is exposed in the vicinity of Milford Peak which is presumably the type locality. The lower part has been dated Carboniferous and the upper, Triassic. It comprises argillites, slates, quartzites, some limestone, and rare volcanic rocks. The Kaslo group, originally named by McConnell (1896a), overlies the Milford with an erosional unconformity, but without discordance of the strata. The relation is also partly intrusive. It is said to form a more or less structureless mass and to consist of lava flows, breccias, tuffs, some intrusive layers, and a minor proportion of sediments, now altered to schists (Cairnes, 1934). The Kaslo is unfossiliferous. The Slocan group, first named by McConnell (1895) in the Slocan area, is now believed to overlie disconformably the Kaslo, but with some erosion of the latter prior to the deposition of the Slocan. It consists of slates, argillites, quartzites, some interbedded tuffaceous rocks, and rare limestone and conglomerate (Cairnes, 1934). The Zincton member consists of argillaceous beds, limy slates, and several limestone bands near Zincton (Hedley, 1945). Some poorly preserved marine fossils, including ammonoids and belemnoids, have been collected and dated Triassic. It is intruded by the Nelson batholith.

26. In the Salmo area, south of the Slocan and Sandon areas, Little (1950) has recently proposed a new classification of the Triassic. The Ymir group is gradational with the Seeman group, below, of Ordovician (?) and later age. It consists of argillite, slate, quartzite, and some limestone. The type locality is presumably on the Salmo River, in the vicinity of Ymir, a little north of the Salmo map area. No fossils have been found, but it has been traced northward into the Slocan group, which it resembles and with which it is correlated by Little (1950). The new name Elise is given by Little

to a formation of andesitic and latite flows, agglomerates, and tuffaceous argillites. The Elise overlies the Ymir conformably and is well exposed on the west slope of Elise Mountain, which is the type locality. It is unfossiliferous but may be of late Triassic or early Jurassic age. It is said to be overlain conformably by the Hall group, now known to be mostly of Jurassic age (Little, 1950), but formerly referred to the Triassic with a query.

Eastern Cordillera

Northeastern British Columbia

27. The Grayling formation, named by Kindle (1944), comprises dark-gray marine shales, with some sandstone. The type locality is on the lower part of Grayling River, a tributary of Liard River. It apparently overlies the Permian disconformably, with possibly no great time gap. It has been dated early Lower Triassic (Kindle, 1944; McLearn, 1945). It has not been recognized in the Tetsa River Valley.

The Toad formation, named by Kindle (1944), conformably overlies the Grayling in the Liard and Tetsa valleys and consists of marine, dark shales, thin-bedded calcareous siltstones, massive siltstone, and some layers of dark limestone. The type locality is on Liard and Toad rivers, near the mouth of the Toad. It carries the *Wasatchites* fauna near the middle and the *Beyrichites-Gymnotoceras* or *Parapopanoceras* fauna high in the formation, but not at the top. The *Wasatchites* fauna (McLearn, 1945) was collected in 1943 by Kindle, on Liard River, and is very close to the *Wasatchites* fauna in the Fort Douglas area, Utah, where it occurs in the *Anasibirites* beds, between the zones of *Meekoceras* and *Tirolites* in the Pinecrest formation (Mathews, 1929). It is of late Owenitan or late, but not the latest, Lower Triassic age.

Nearly a quarter of a century ago, the *Beyrichites-Gymnotoceras* fauna was collected in what were then little-known valleys in northeastern British Columbia, by a party of an oil exploration company. Its importance was not realized at the time, and it was not studied. In 1943, however, it was rediscovered by Hage (1944), Williams (1944), and Kindle (1944) in the Sikanni Chief, Tetsa, and Liard River valleys. Large collections of this fauna made by McLearn in 1944 contain species of *Longobardites* and *Beyrichites* similar to or identical with species in the late Anisian or Paraceratitan fauna in the Star Peak formation of the American Canyon, West Humboldt Range, Nevada (McLearn, 1948). Some genera, however, very common in the Nevada fauna, including *Anolcites*, *Nevadites*, *Protrachyceras*, and *Epigymnites*, are missing in British Columbia. Whether this is purely a geographic feature or whether it means some difference in age is not known. Zoning of Anisian deposits is not yet satisfactorily established. This fauna also closely resembles one on the island of Spitzbergen described by Mojsisovics (1886), particularly in species of *Parapopanoceras* and *Gymnotoceras*.

The Liard formation, named by Kindle (1948), comprises marine, thick-bedded, gray, fine, calcareous sandstone, arenaceous limestone, limestone, and some shale and siltstone. The contact with the Toad is in most places conformable, and the type locality is on Liard River, near Hades Gate. It occurs in the western but disappears in the eastern sections, unless it is represented in the east by a few feet of limestone and calcareous sandstone at the top, or just on top of the Toad formation. On the Liard the change takes place between the mouth of Crusty Creek and the mouth of Toad River (Kindle, 1944) and in the Tetsa Valley, just east of mile 378, Alaska Highway (McLearn, 1948). The sudden disappearance to the east of this formation suggests pre-Jurassic or pre-Cretaceous erosion on a fairly large scale prior to the deposition of the basal, Jurassic or Lower Cretaceous beds of the overlying Garbutt formation.

The *Nathorstites* fauna, first collected on Liard River (McConnell, 1891), occurs in beds placed by Kindle (1944) in his Liard formation. It is of Ladinian, late Middle Triassic, or early Karnian, very early Upper Triassic age.

Triassic beds are missing on the lower part of the Liard River and on the Petitot River.

28. The upper part of the Toad formation, carrying the *Beyrichites-Gymnotoceras* fauna, is well exposed on McTaggart Creek, near Mount Hage on the south side of Sikanni Chief Valley, and it also occurs in the lower part of

the Fourth Gully on Mount Wright in the Halfway Valley (McLearn, 1947a; 1948). At both localities the Toad is overlain conformably by the "Flagstones" (McLearn, 1947a; 1948), which on McTaggart and Hage creeks comprise thin-bedded, flaggy, and massive siltstones. In the Fourth Gully of Mount Wright they consist of similar siltstones overlain by massive, gray, calcareous, fine sandstones and limestones, similar in lithology to the beds of the Liard formation and with brachiopods similar to those in that formation. Conformably overlying the "Flagstones" are the "Dark siltstones" (McLearn, 1947a; 1948), which consist of dark, calcareous siltstone, dark shale, and dark limestone in the Third Gully of Mount Wright in the Halfway Valley and on Hage Creek near Mount Hage in the Sikanni Chief Valley. In both valleys they contain the *Nathorstites* fauna. Overlying the "Dark siltstones" conformably are the "Gray beds" (McLearn, 1947a), studied on the east slope of Mount Hage in the Sikanni Chief River Valley and between the Second and Third Gullies and west of the Second Gully of Mount Wright in the Halfway River Valley. They consist mostly of gray, thick-bedded, massive calcareous sandstones and limestones lithologically similar to the Liard formation. On the east slope of Mount Hage the basal beds of the "Gray beds" carry the *Nathorstites* fauna. So far no diagnostic fossils have been found in the upper part of the "Gray beds" in the Sikanni Chief and Halfway valleys. As the *Nathorstites* fauna is found in the lower part of the "Gray beds" and in the Liard formation and as brachiopods like those in the Liard and basal "Grey beds" occur in the "Flagstones" it may be inferred that the "Flagstones", "Dark Siltstones," and basal "Gray beds" together are equivalent to the Liard formation (McLearn, 1947a).

Lying conformably above the "Gray beds" in both Halfway and Sikanni Chief valleys are the Pardonet beds. They are better known in the Peace River Foothills, where they were first studied. On Sikanni Chief River they are well exposed below the mouth of Chicken Creek where they consist of dark, calcareous siltstones and limestones. The lower part carries *Halobia* and *Gryphaea* of possibly late Karnian age, although no short-ranging diagnostic species are present. Above are beds with *Halobia* cf. *dilatata* Kittl, probably of Norian age. In the upper part is a mid-Norian (late Haloritan) fauna with *Monotis alaskana* Smith, *Himavatites columbianus* McLearn, *Parajuvavites*, and *Alloclionites*. The late Norian zone of *Monotis subcircularis* Gabb does not occur here, but farther west, on Mount Hage, beds with this species immediately overlie beds with *M. alaskana*. The Pardonet beds are overlain, probably disconformably, by the Jurassic shales of the Fernie group.

It may be noted that higher beds, including the upper Triassic, do not extend as far east or northeast as the lower ones. The *M. subcircularis* beds disappear first, then all the Pardonet beds, and finally everything above the Toad formation. No Triassic has been found to the northeast in the lower part of the Liard River. This may be to some extent an offlap, due to west or southwesterly retreat of the sea, but may also be partly the result of pre-Jurassic erosion along the eastern or northeastern margin of the Triassic terrains.

29. The Triassic was first recognized on Peace River by Selwyn in 1875 (Selwyn, 1877) when he collected specimens of *Monotis subcircularis* near the mouth of Clearwater River on the outer edge of the mountains. He also found a few Triassic fossils on the south side of Peace River, south of Gold Bar in the Foothills. Because of the short time at his disposal he passed by all the good fossil localities, and more than 40 years passed before they were discovered. McConnell (1896b) also found *Monotis subcircularis* in the mountains, but he, like Selwyn, overlooked the important Triassic localities in the Foothills.

Investigation was resumed in 1917 (McLearn, 1918), and the succession in the Peace River Foothills is now fairly well known. The lowest Triassic beds known are the "Dark Siltstones". They are best exposed on the Beattie Ledge (McLearn, 1940b) and comprise mostly dark siltstones, with some interbedded, dark limestone. They enclose the *Nathorstites* fauna which includes species of the ammonoid genera *Nathorstites*, *Thanamites?*, *Lobites*, *Sageniites*, *Proarcestes*, *Protrachyceras*, *Paratrachyceras*, *Silenticeras*, and *Asklepioceras*. This fauna is

of Ladinian or earliest Karnian age (McLearn, 1947a). The "Dark Siltstones" are overlain conformably by the "Gray beds", well exposed at the Beattie Ledge, Beattie Hill, Jewitt Spur, Dry Canyon shoulder, Pardonet Hill, and other localities (McLearn, 1940a; 1940b; 1941). They consist principally of thick-bedded, gray, calcareous sandstones and limestones lithologically similar to the Liard formation. In ascending order they contain the *Nathorstites*, the Mahaffy Cliffs or Red Rock Spur, and *Lima? poyana* faunas. Barren beds of considerable thickness lie between the fossiliferous beds. In the "Gray beds" the *Nathorstites* fauna comprises mostly pelecypods and brachiopods. The Mahaffy Cliffs or Red Rock Spur fauna or faunas consist mostly of pelecypods resembling the German Triassic and are of Ladinian or very early Karnian age. The *Lima? poyana* fauna comprises mostly pelecypods and the brachiopod "*Terebratula*" cf. *julica* Bittner and is thought to be of early Karnian age.

The Pardonet beds conformably overlie the "Gray beds" and consist mostly of dark siltstones with some dark limestone; sandstone is rare. Several faunal zones are known, separated by barren zones. A composite faunal succession, based on a study of the sections on Pardonet Hill (P.H.) and the west slope of Brown Hill (B.H.) is as follows: (McLearn, 1947b):

Monotis subcircularis Gabb (P.H., B.H.)
Himavatites, Distichites, M. alaskana (P.H., B.H.)
Cyrtopleurites cf. *bicrenatus* Hauer, *H.* cf. *dilatata* Kittl (B.H.)
"Styrites" ireneanus (P.H.)
Tropites sp. (P.H.)
Stikinoceras (P.H., B.H.)

It is inferred that the *Stikinoceras*, *Tropites*, and *"Styrites"* faunas are all phases of the late Karnian *Tropites* fauna, that the *Cyrtopleurites* cf. *bicrenatus* fauna and the *Himavatites* fauna are of early Norian (Haloritan) age, and the *Monotis subcircularis* fauna of late Norian (*Pinacoceratan*) age (McLearn, 1947b). The contact with the overlying Lower Jurassic (Sinemurian) beds of the Fernie group is mainly that of a disconformity and possibly, to a minor extent, that of an erosional unconformity.

Hard, black, calcareous shales were recorded from the eastern border of the limestone ranges in the vicinity of Pine River and assigned by Dawson (1881) to the Triassic. Williams and Bocock (1932) collected *Monotis subcircularis* from near the mouth of Mountain Creek and presumably from the top of the Pardonet beds. They also collected the *L.? poyana* fauna on a hill at the mouth of Mountain Creek in the Pine River Valley.

Dark fissile siltstones near Wapiti Lake contain *Halobia* and may be part of a southeastern extension of the Pardonet beds. Ganoid fishes have been collected in the Ganoid Range (Laudon *et al.*, 1949).

Athabasca River to Wapiti River

30. Allan (1933) has described a facies uncommon and unusual in the Triassic of western Canada. On Mowitch Creek northwest of Jasper Park and in the eastern part of the Rocky Mountains he has recorded what is probably a shore phase of the Triassic sea, including red beds and gypsum, overlain by yellow- to buff-weathering shales and gypsiferous beds. They have been correlated with the similar beds in the deep well at Bonanza, Alberta (Allan and Stelck, 1940). These beds are overlain by gray limestone and sandstone, comparable with the limestone above the red beds in the Bonanza well. No fossils have been found, and it is difficult to determine the age of the beds. If the gypsum beds on Mt. Cinquefoil (Warren, 1945) overlie the Whitehorse member they are probably of post-Anisian age. Moreover, as the red and gypsum beds are probably a shore phase and as they have not been reported from the Foothills, where the section is fairly well known and the highest beds are those of the Anisian Whitehorse formation (Lang, 1947; Irish, 1947), it follows that they may be of post-Anisian age. As Allan (1933) and Warren (1945) have suggested, the gray limestones and sandstones overlying the red and yellow beds in the Mowitch River section may be equivalent to some part of the "Gray beds" in the Peace River Foothills.

31. On Vine Creek, near Snaring Station, in the eastern part of the Rocky Mountains. Parajas (1931) has collected *Monotis* cf. *subcircularis* Gabb but does not describe the

section. The *Monotis*-bearing beds are probably higher than any of the beds in the Mowitch Creek section described by Allan.

32. In the Foothills in the Brûlé, Entrance, Moon Creek, Pierre Greys, and other areas north of Athabasca River, the Spray River formation overlies the Mississippian Rundle formation, disconformably. It is said (Lang, 1947; Irish, 1947) that a lower member comprises interbedded siltstone and sandstone, correlated tentatively with the Sulphur Mountain member of the Spray River formation in the Banff area. The limestone and dolomite that overlie the siltstone and sandstone member are thought by both Lang and Irish to constitute the Whitehorse member of this formation. In the Moon Creek map area, Irish (1947) collected fossils of Anisian or early Middle Triassic age from this member. Warren's correlation of the Whitehorse with the "Gray beds" of the Peace River Foothills cannot be accepted if the Whitehorse is of Anisian and the "Gray beds" of Ladinian or very early Karnian age.

Lang (1947) states that the Whitehorse is overlain, without discordance, by the Jurassic Fernie group.

Bow River to Athabasca River

33. The name Spray River has been given by E. M. Kindle (1924) to a formation formerly designated the Upper Banff shale. It is said to consist of shale, black carbonaceous shale, and thin-bedded limestone, and the type locality is the Spray River gorge, 7 miles from Banff. The Upper Banff shale had been dated late Paleozoic, but Girty assigned it a Lower Triassic age after studying fossils collected by E. M. Kindle, L. D. Burling, and H. W. Shimer (Lambe, 1916). This formation has been divided into two members by Warren (1945). The lower or Sulphur Mountain member is well exposed in the Spray River gorge at the foot of Sulphur Mountain and consists of "dark gray to black, laminated shales, and dark gray, fine-grained limestones or dolomites" (Warren, 1945). The pelecypod species *Claraia stachei* (Bittner) is recorded by Warren from near the base of this member, and flattened specimens of *Ophiceras*, *Proptychites*, and *Otoceras* from about the same horizon. This fauna is presumably of early Lower Triassic and of Otoceratan age in Spath's chronology. *Flemingites?* of late Lower Triassic and about Owenitan age is recorded by Warren from near the top of this member. The beds of the Sulphur Mountain lie disconformably on the Pennsylvanian (and Permian?) Rocky Mountain formation or the Mississippian Rundle formation (Warren, 1945).

The upper and Whitehorse member consists of light-gray to whitish limestones, dolomites, sandy dolomites, calcareous sandstones with in some places an admixture of darker shales. Warren also notes, in the north, the occurrence of gypsum and other evaporites. If these evaporites in the north definitely overlie the typical Whitehorse, it may prove desirable to exclude them from this member and recognize them as a distinct unit. The type locality is on Whitehorse River. *Gymnotoceras blakei* (Gabb), *Daonella* sp., and other species have been collected, indicating a Middle Triassic age. Warren infers that the Whitehorse member rests disconformably on the Sulphur Mountain member, with evidence of some erosion along the contact. It is overlain disconformably by the Jurassic Fernie group.

In some parts of the Foothills between the Bow and Athabasca rivers, the Triassic cannot be readily identified or delimited. Some part of the section mapped as Fernie group in the Fall Creek and Tay River map areas may be Triassic (Henderson, 1944; 1945). No Triassic is reported from the Alexo and Saunders map areas (Erdman, 1950).

South of the Bow

Only the Lower Triassic Sulphur Mountain member has been recognized in the Ribbon Creek map area (Crockford, 1949), where red-weathering, mostly thin-bedded, argillaceous siltstones together with some impure limestone and dolomite are recorded.

Both members are recognized in the Highwood-Elbow area (Allan and Carr, 1947). Some basal phosphatic beds are included in the Sulphur Mountain member, and the Whitehorse consists of "light gray, white, and pinkish sandy limestones, cherts and silicified coquinas". Some gypsum also is said to be present. The only fossil cited is *Lingula* sp. The Spray River of this area overlies un-

divided Paleozoic with an erosional unconformity and underlies the Fernie group with a similar contact.

No Triassic has been recognized in the Moose Mountain area. Beach (1943) notes, however, that the "black conglomerate found in Canyon Creek suggests that Triassic rocks had been present, but were reduced to rubble before the advance of the Jurassic seas."

In the southern Foothills, in the Gap map area, dark limestone, dolomitic limestone, and dolomite have been doubtfully referred to the Triassic (Douglas, 1950). No fossils have been found.

In the Fernie area shales with *Lingula*, poorly preserved ammonites, and fragmental vertebrate remains may be of Triassic age (H. Frebold, personal communication). They are difficult to separate from the shales of the Fernie group.

The Plains

34. The Triassic has been found in the section penetrated by the Guardian well No. 1 at Bonanza, Alberta, on the Plains, a little south of Peace River and near the border between British Columbia and Alberta. Allan and Stelck (1940) assigned beds from 4774 to 5459 feet to the Triassic, which consist of:

	Feet
Limestone, cherty at top, becoming dolomitic below	346
"Red beds"	135
Limestone	95
"Red beds"	109

The "Red beds" comprise "calcareous, gypsiferous shales, carrying beds of gypsum, brown dolomite, and blue limestone"; they have not been observed in the Peace River Foothills, but may represent a shore phase of some part of the Triassic occurring there. On the basis of similar lithology, Allan and Stelck (1940) correlate them with the "red beds" and gypsum on Mowitch Creek, north of Jasper.

This well was carried to a lower horizon, and Webb (1951) states that the red gypsiferous limestones and associated beds are underlain by gray siltstones, fine sandstones, and shales of Lower Triassic age. Webb (1951, Fig. 9) records Triassic as far east, on the northern Plains, as the Town of Peace River.

In the southern part of Manitoba and possibly buried below Jurassic, Cretaceous, and Paleocene strata in southern Saskatchewan are the "red beds" and gypsum of the Amaranth formation (Wickenden, 1945). They resemble the beds of the Spearfish formation in South Dakota, Wyoming, and Nebraska, but their age is uncertain.

Arctic Regions

35. Triassic sandstones, shales, and limestone are known on Axel Heiberg and Ellesmere Islands. The fauna, described by Kittl (1907), shows some resemblance to Triassic faunas of Spitzbergen and Bear Island, but contains no *Nathorstites*. Triassic may occur on other islands in the Canadian Arctic; no definite evidence, however, has been obtained.

Appalachian Region

36. In the Maritimes of eastern Canada the Triassic occurs on both sides of the Bay of Fundy. On the northwest shore and in the province of New Brunswick it outcrops in small areas from Grand Manan Island to Waterside on Chignecto Bay. The greater part of the Grand Manan Island is underlain by North Mountain basalt. At other localities red, and, in places, yellow sandstones and shale with some conglomerate occur. At Quaco, or St. Martins, the thick Quaco conglomerate, named by Powers, lies between Lower and Upper red sandstones (Powers, 1916).

37. On the southeast side of the Bay of Fundy, in the province of Nova Scotia, the following formations have been described by Powers (1916): Scots Bay formation, North Mountain basalt, and Annapolis formation. The lowest, the Annapolis formation, outcrops in the Annapolis-Cornwallis Valley, on part of the north shore of Minas Channel and on both the north and south shores of Minas Basin. It consists of red sandstone, calcareous sandstone and shale, and lesser proportions of green sandstone and shale and some conglomerate. In the vicinity of Five Islands a zone of volcanic rocks occurs near the top of this formation. In a large part of the region the Annapolis can be divided into the Wolfville sandstone below and the Blomidon shale above (Powers,

1916). It rests unconformably in places on late Paleozoic and in other places on Precambrian formations.

The Annapolis is followed by the North Mountain basalt, which underlies the North

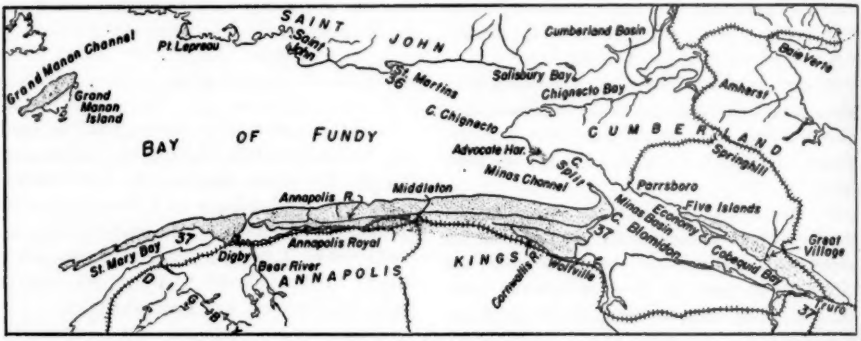

FIGURE 2.—INDEX AND OUTCROP MAP, EASTERN CANADA.

Stippled areas record distribution of Triassic in Bay of Fundy area. 36, 37 refer to columns in Plate1.

Mountain upland and also is found in small patches on the north side of Minas Channel and of Minas Basin. It consists of basalt flows, in part amygdaloidal, and some greenish-white ash.

The Scots Bay formation overlies the North Mountain basalt on Scots Bay. There is only a remnant, which consists of white, very calcareous sandstone, gray sandstone in places replaced by chert, shale, and some greenish sandstone and shale (Powers, 1916).

These Acadian Triassic formations contain fossil fish and bivalved crustaceans and plant remains and are, apparently, of nonmarine origin. They have been correlated with the Newark group of Connecticut and other parts of the eastern United States. Their age lies somewhere in the later half of the Triassic period (Powers, 1916).

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CORRELATION OF THE JURASSIC FORMATIONS OF CANADA

BY HANS FREBOLD

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INTRODUCTION

The correlation chart of the Jurassic system of Canada is Number 8d of a series of correlation charts prepared under the auspices of the Committee on Stratigraphy of the National Research Council.[1]

The various regions of Jurassic rocks in Canada have not all been studied with the same detail. The Jurassic of Vancouver Island and the Fernie group of Alberta and eastern British Columbia are now fairly well known, but elsewhere much remains to be done. Systematic stratigraphic investigations on a paleontological basis are being pursued by members of the Geological Survey of Canada, and it is hoped that more and finer subdivisions will be forthcoming, even in the regions of high structural complexity. Such investigations will undoubtedly necessitate changes in the present chart from time to time.

Much of the information in this account is based on unpublished identifications of fossils and, in the case of the Fernie group, on the writer's field work.

Arkell's subdivision of the Jurassic system of Europe (1946, p. 1–34) has been used as a basis for this review. This will facilitate comparison and correlation with other parts of the world.

The author is very grateful to Dr. Ralph W. Imlay, formerly in charge of the preparation of this Canadian chart, for notes and information kindly turned over by him. The author wishes to thank Dr. F. H. McLearn for valuable personal communications and discussion, and also Dr. P. S. Warren who made some important collections from the Fernie group available for study.

[1] Dunbar, C. O., *et al.* (1942) *Correlation charts prepared by the Committee on Stratigraphy of the National Research Council*, Geol. Soc. Am., Bull., vol. 53, p. 429–434.

ANNOTATIONS

1. *Between Kyuquot Sound and Esperanza Inlet, Vancouver Island, and Parson Bay region*

The Harbledown formation in the area surrounding Parson Bay, Queen Charlotte Sound (northeastern end of Vancouver Island), belongs to the Sinemurian stage of the Lower Jurassic according to Crickmay (1928; 1931, p. 23, 24). The ammonites *Arniotites* and *Melanhippites*, which Crickmay described, are so poorly preserved that the age of this formation remains rather doubtful. The basal contact with the lithologically similar Triassic Parson Bay formation may be a disconformity.

Both Lower and Upper Jurassic fossiliferous rocks are present in the Kyuquot-Esperanza area of the northwestern part of the island (Jeletzky, 1950). The following description of the sequence in this part of the island is based on the investigations of Jeletzky, who has kindly supplied the author with unpublished information on his more recent explorations. The Lower Jurassic comprises a lower assemblage with *Trigonia* ex gr. *costata* Sowerby, *Gervillia*, and *Pholadomya*, and an upper one with *Harpoceras*, *Fanninoceras*, and *Trigonia*. The latter is an equivalent of the *Harpoceras-*

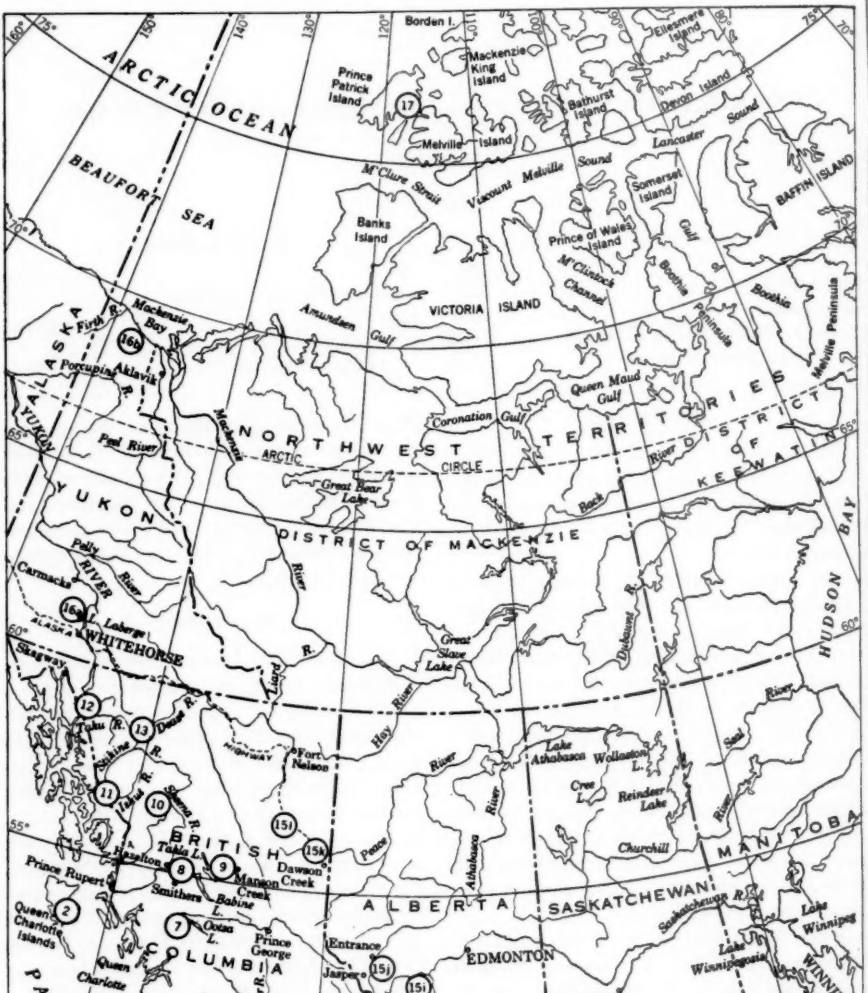

FIGURE 1.—JURASSIC LOCALITIES IN CANADA

Fanninoceras fauna of the Maude formation of the Queen Charlotte Islands.

This fauna belongs to the Toarcian or upper part of the Lower Jurassic. The volcanic tuffs and breccias with lava flows, which lie between the fossiliferous Toarcian and the marine Upper Triassic, probably belong to older parts of the Lower Jurassic. The contact with the Upper Triassic is an erosional nonsequence or possibly even a structural unconformity.

There is a hiatus between the Toarcian and the Callovian which apparently includes the whole of the Middle Jurassic.

The beds with *Cadoceras* ex gr. *doroschini* Eichwald belong to the Callovian and are supposed to be equivalent to higher parts of the Shelikof formation in Alaska. They are, according to Jeletzky, only a little younger than the *Seymourites* fauna of the Late Yakoun formation of the Queen Charlotte Islands. Another questionable Callovian fauna, consisting of *Oppelia* ex gr. *subradiata* Sowerby *sensu lato*, "*Perisphinctes*," *Phylloceras* sp., *Cylindroteuthis*, *Pachyteuthis*, and others, needs further investigation as its exact stratigraphic position is unknown. Plant remains found in association with this fauna support the view that the beds concerned are of Late Yakoun age and therefore belong to the Callovian (Bell *in* Jeletzky, 1950, p. 25, 30).

No index fossils have been found in the lower shale member of Division A, and it is questionable whether it really belongs to the Callovian.

The lower part of the sandstone member of Division A with a lower fauna consisting of *Cardioceras* ex gr. *lillooetense* Reeside and *Aucella* ex gr. *bronni*, and a higher one with the same *Aucella* and *A. bronni* var. *leguminosa* Rouiller, belongs to the Oxfordian. The upper part of the sandstone member may be either Oxfordian or Early Kimmeridgian, whereas the upper shale member is supposed to be Early Kimmeridgian in age.

The gap between Divisions A and B may comprise both Late Kimmeridgian and Early Portlandian. Division B, which has been subdivided paleontologically into a lower zone with *Aucella* ex gr. *russiensis* Pavlow and an upper one with *Aucella* ex gr. *rugosa* Fischer, belongs to the Portlandian.

There is an erosional disconformity between Division B and the typical marine Early Neocomian.

2. *Queen Charlotte Islands*

The Jurassic of the Queen Charlotte Islands is divided into the Maude and Yakoun formations.

The Maude formation consists of argillites, sandstones, quartzites, calcareous beds, tuffs, and agglomerates lying conformably below the Yakoun formation. The base of the Maude formation is not exposed.

The lower part of the Maude formation consists of 500 to 1500 feet of argillite, quartzite, and calcareous beds. McLearn (1932a, p. 59–80; 1949, p. 9) has described two Lower Jurassic faunas from these beds, the *Fanninoceras* fauna and the *Harpoceras* fauna. The *Fanninoceras* fauna contains some species of *Fanninoceras*, a number of pelecypods, and brachiopods. The *Harpoceras* fauna is characterized by species of *Harpoceras* and *Dactylioceras*. The relative stratigraphic position of these two faunas to one another is not known. The *Harpoceras* fauna belongs to the Toarcian stage of the upper Lower Jurassic, and the *Fanninoceras* fauna is probably of the same age.

McLearn (1949, p. 9) says that the lowermost part of the Maude formation may also include Triassic and some pre-Toarcian Jurassic beds; and Crickmay (1931, p. 24–26) places *Arniotites vancouverensis* Whiteaves (Whiteaves, 1889a, p. 146–147, Pl. 19, fig. 2), formerly described as Triassic, in the Sinemurian stage of the Lower Jurassic.

The higher beds of the Maude formation, which consist of 600 to 800 feet of argillites and fine agglomerates, contain only rare belemnoids. They may possibly belong to the Early Bajocian stage of lower Middle Jurassic.

The Yakoun formation contains two well-characterized faunas which have been dealt with by McLearn (1927, p. 71–73; 1929b, p. 1–27; 1932a, p. 51–59; 1949, p. 10–17).

The lower part consists of more than 200 feet of marine tuff, agglomerate, tuffaceous shale, and sandstone, and contains a typical Middle Bajocian fauna with *Stephanoceras*, *Teloceras*, *Zemistephanus*, *Kanastephanus*, *Itin-*

saites, and *Defonticeras*. Equivalents of this Early Yakoun fauna are present almost everywhere in the "Rock Creek Member" of the Fernie group in Alberta and British Columbia.

The middle part of the formation—1200 to 1500 feet of tuff and agglomerate with rare belemnoids and brachiopods—may possibly belong to the time range of Late Bajocian and Bathonian.

The upper part of the Yakoun, consisting of more than 430 feet of marine sandstone and shale, contains many pelecypods and a number of species of *Seymourites*, which indicate a late Early Callovian age. *Seymourites* has also been found in the Fernie group of Ribbon Creek, Alberta, and probably also in the Fernie group of the Blairmore region, Alberta. According to Jeletzky (1950) the *Seymourites* fauna of the Queen Charlotte Islands is only a little older than the *Cadoceras doroschini* fauna of Vancouver Island.

No Jurassic beds younger than those containing this *Seymourites* fauna have been found on the Queen Charlotte Islands. The Yakoun formation is here unconformably overlain by the Haida formation which is of Albian (high Lower Cretaceous) age. The time interval between the Late Yakoun formation and the Haida formation is equal to a large part of the Upper Jurassic and Lower Cretaceous.

3. *Southwest Hope Map Area*

The Cultus formation (Daly, 1912, p. 516–518) consists of black to dark-gray argillite with a few lenses of sandstone. Daly suggested a Triassic age for this formation, but the "*Arniotites vancouverensis* Whiteaves?" reported from the Cultus formation indicates that the beds probably belong to the lower part of Lower Jurassic, though beds of Triassic age may be present also in the Cultus formation.

Probably younger than the Cultus formation is the Tamihi group which consists of conglomerates, grits, sandstones, and quartzites.

In the Tamihi group, or in beds belonging to the Cultus formation, *Stephanoceras ?* and *Aucella erringtoni* Gabb have been found (Daly, 1912, p. 519). These fossils may indicate the presence of Middle and Upper Jurassic rocks in this region.

4. *Harrison Lake Area*

The lower part of the Jurassic in the Harrison Lake area consists of about 9000 feet of volcanics according to Crickmay (1930a, p. 37).

The Mysterious Creek formation consists of 2500 feet of black shale overlying the Middle Jurassic volcanics. Crickmay (1930a, p. 37; 1931, p. 41, 42) mentions three faunas—a lower one with "Macrocephalitids of *Catacephalites* aspect"; a middle one, about 1500 feet above the base, with *Cadoceras*, *Paracadoceras*, and *Pseudocadoceras*; and an upper one, near the top of the formation, with *Lilloettia* and *Buckmanniceras*. The fauna with *Cadoceras*, *Paracadoceras*, and *Pseudocadoceras* is Callovian in age and contains species identical with or very similar to species in the Alaskan Chinitna shale and Shelikof formation (R. W. Imlay, Personal Communication). *Lilloettia* also belongs apparently to the Callovian, but the age of the lower fauna with the undescribed "Macrocephalitids of *Catacephalites* aspect" is questionable.

The Billhook formation consists of 1800 feet of tuff and contains trigoniids and a "Cardioceratid near *Cadoceras*" (Crickmay, 1930a, p. 37, 39, 40; 1931, p. 44). As this ammonite was not described, the age of this formation also is uncertain though Crickmay (1931, p. 44) placed it in the Late Callovian.

The Agassiz group has a thickness of about 8000 feet, and its basal part—a thick conglomerate called the Kent formation—rests unconformably upon the Lower Upper Jurassic (Crickmay, 1931, p. 45). The upper part of the Agassiz group, called the Agassiz Prairie formation, consists mainly of 5000 feet of dark argillite. It has yielded *Phylloceras* and a *Cardioceras*, which indicate the presence of Oxfordian (Crickmay, 1930a, p. 58–60, 64; 1931, p. 45, 49).

5. *Ashcroft Area*

In the Ashcroft area the lower part of the Jurassic strata is formed by the Thompson group, 1837 feet thick. This series has been divided into two formations. The lower, the Ntlakapamux formation, consists of calcareous arkose and conglomerate, and the upper, the Opuntia formation, is black shale. Crickmay

(1930b, p. 37; 1931, p. 32, 33) mentions *Fontannesia* and *Kallistephanus* from the Thompson series and designates this part of the strata as Sonninian (lower Middle Jurassic).

The overlying upper part of the Jurassic, the Ashcroft group, 3090 feet thick, comprises conglomerates, black shale, and sandstone. The Minabariet formation of this group, from which Crickmay (1930b, p. 27, 62; 1931, p. 42, 68) has mentioned *Gowericeras*, belongs to the Callovian. Some other very poorly preserved ammonites, which may belong to *Seymourites*, were collected by Duffell (Geological Survey of Canada, Ottawa) from the same area in 1945. These seem to confirm this age determination.

Unfortunately the poor preservation of all guide fossils in this area makes the age determinations uncertain.

6. *Tyaughton Lake Area*

The Lower Jurassic of the Tyaughton Lake area consists mainly of dark argillite, with limy concretions locally, and shale, in part calcareous. Thin bands of limestone, sandstone, and small pebble conglomerate were also noted. The Lower Jurassic is partly in faulted contact with the Upper Triassic Tyaughton group. In places, however, it appears to overlie the Tyaughton group conformably (Cairnes, 1943, p. 5). No continuous section through the Lower Jurassic has been found, but the fossils allow a division of the strata into zones (Frebold, 1951, p. 11–14). The Hettangian stage is indicated by the *Psiloceras* beds with *Psiloceras canadense* Frebold, and the *Schlotheimia* beds with *Schlotheimia* (*Scamnoceras*) cf. *acuticosta* Buckman. Beds of apparently the same age are present in the lower part of the Sunrise formation in Nevada. *Psiloceras* is also found in the lower part of the Laberge series, Yukon.

The Early Sinemurian stage is represented by the zones of *Vermiceras scylla*, *Vermiceras latisulcatum*, *Coroniceras bisulcatum*, *Agassiceras* cf. *scipionanum*, and *Asteroceras* cf. *stellare*. The succession of ammonite zones is apparently the same as in Europe. Part of this succession is also indicated in the Sunrise formation of Nevada where *Ammonites bisulcatus* Bruguière, *A. rotiformis* Sowerby, and others have been found (Muller and Ferguson, 1939, p. 1611).

With the exception of a fragmentary "*Harpoceras*" which indicates the presence of Upper Liassic, no higher Lower Jurassic rocks have been found as yet in the Tyaughton Lake area (Frebold, 1951, p. 13).

Middle Jurassic is indicated by some sphaeroceratids, which were found in dark-gray argillaceous beds. No contact with older or younger rocks has been observed.

No age determination of the Taylor group has been possible. The group comprises altogether several thousand feet of chiefly conglomeratic rocks, finer-grained, clastic materials and minor intercalations of volcanic rocks. Poorly preserved plant remains have suggested a Jurassic age—perhaps high Middle or low Upper (Cairnes, 1943, p. 6).

A *Cadoceras* which was found loose may indicate the presence of Callovian rocks in this area.

The Eldorado group comprises both Upper Jurassic and Lower Cretaceous sedimentary rocks (Cairnes, 1943, p. 7). The Jurassic part of the group consists mainly of dark argillaceous beds. Occasional limy concretions and thin dark limestone beds were observed. *Cardioceras* cf. *cordiforme* Meek and Hayden and *Aucella* ex gr. *bronni* Rouillier indicate the presence of Oxfordian, and *Aucella* ex gr. *mosquensis* von Buch denotes Late Kimmeridgian or Earliest Portlandian. Jeletzky (1950, p. 35) has correlated the beds containing *Cardioceras* cf. *cordiforme* and *Aucella* ex gr. *bronni* with his Division A on Vancouver Island.

Beds of Oxfordian age with *Cardioceras canadense* Whiteaves, *C. lillooetense* Reeside, *C. whiteavesi* Reeside, and *Aucella* ex gr. *bronni* are also reported from the head of Big Creek, about 90 miles northwest of Lillooet (Reeside, 1919, p. 9, 11, 20, 27, 33, Pl. 17).

They are probably equivalent also to the beds with *Cardioceras* in the Hazelton group of Groundhog area and to the Agassiz group in the Harrison Lake area, British Columbia.

7. *Whitesail Area*

The Hazelton group in this area is made up of both sediments and volcanics. The detailed

stratigraphy is not yet known and apparently varies from place to place.

Fossil collections made by Duffell (Geological Survey of Canada, Ottawa) within this region show that at least Earliest and Middle Bajocian are present. This Earliest Bajocian contains *Tmetoceras regleyi* Dumortier, "*Polymorphites*" cf. *senescens* Buckman, *Pleuromya* cf. *carlottensis* Whiteaves, *Pleuromya* sp., *Parallelodon* sp. nov., a few gastropods, and *Rhynchonella* (Frebold, 1951, p. 18–20, Pl. 15, figs. 1–5). Some species of *Stephanoceras* associated with *Terebratula*, *Trigonia*, and *Pinna* indicate the presence of Middle Bajocian. Incompletely preserved ammonites collected in the same area may belong to the Callovian.

8. *Hudson Bay Mountain and Smithers Area*

In this region the Hazelton group has been divided by Armstrong (1944a) into five map units: (1) volcanic division (Lower Jurassic), (2) marine sedimentary division, argillite, sandstone, and limestone (Middle Jurassic), (3) volcanic division (Middle or Upper Jurassic). (4) continental sedimentary division (Upper Jurassic and Lower Cretaceous), (5) volcanic division (Lower Cretaceous or higher).

The Middle Jurassic sedimentary division has a thickness of at least 500 feet and contains *Sonninia hansoni*, *Sonninites silveria*, *S. skawahi*, *Guhsania bella*, *G. ramata*, *Ctenostreon gikshanensis*, *Lima tizglensis*, *Plagiostoma hazeltonense*, *Trigonia guhsani*, *Serpula socialis* Goldfuss, etc. (McLearn, 1926; 1927, p. 65). This fauna is of Late Sonninian to Early Stepheoceratan or Middle Bajocian age.

Armstrong (1944a) mentions the presence of shells and plants in the upper sedimentary division, which is at least 5000 feet thick. No detailed information about these fossils is available; therefore the age determination as partly Upper Jurassic is somewhat doubtful.

The Hazelton group in this area has a thickness of possibly 10,000 feet.

Hazelton area.—The two lower members of the Hazelton group, which are developed in the Smithers and Hudson Bay Mountains area, are either missing or have not been recognized in the Hazelton area. The lowermost member of the Hazelton group in this area is the volcanic division which probably is of Middle or Upper Jurassic age. Younger than these volcanics is "the Upper Jurassic and Lower Cretaceous sedimentary division" which consists of at least 5000 feet of interbedded continental and marine strata. According to Armstrong (1944b) fossil plants include species of both Kootenay and Blairmore age. Armstrong has reported a fauna of "late Upper Jurassic age" in beds apparently younger than some beds containing fossil plants of Kootenay age.

Younger than this sedimentary division is another volcanic division of Lower Cretaceous age or still younger.

9. *McConnell, Takla, Manson Creek, Fort Fraser Areas*

In this area of central British Columbia the Jurassic is part of the Takla group, which includes rocks of Upper Triassic age. The Jurassic is best known in the McConnell Creek map area (Lord, 1948, p. 15–28), where the Takla group comprises a conformable assemblage of more than 33,000 feet of volcanic and sedimentary rocks. The lower division has a thickness of about 18,000 feet. It probably belongs to the Upper Triassic.

The upper division consists of an older part, which includes more than 18,000 feet of volcanic rocks, and a younger one composed of much more than 5000 feet of marine sediments, interbedded with minor volcanic rocks, carbonaceous strata, and coal. The sediments consist mainly of graywackes, conglomerates, shales, and argillites, but limestone also occurs.

In the McConnell Creek map area the following subdivisions are indicated: (a) upper part of Lower Liassic, by *Platypleuroceras* ex gr. *natrix* Zieten, (b) Upper Liassic, by *Pseudogrammoceras* ex gr. *saemanni*, *Reynesoceras* ex gr. *ragazzonii* Hauer, *Haugia* sp. aff. *grandis* Buckman, (c) Middle Jurassic by *Stephanoceras* sp., *Witchellia*, *Trigonia* (*Vaugonia*), and (d) middle Upper Jurassic (Oxfordian) by *Cardioceras* aff. *praecordatum* Douvillé, *Cardioceras* aff. *scarburgense* Young and Bird, *Perisphinctes* div. gen.

In the Takla map area (Armstrong, 1945) the Takla group consists of more than 5000 feet of interbedded volcanic and sedimentary rock and comprises both Upper Triassic and Jurassic strata. Poorly preserved ammonites indicate the presence of Lower Liassic ("*Arnioceras*")

and Upper Liassic ("*Harpoceras*"). No Jurassic fossils have been found in the Takla group of the Manson Creek and Fort Fraser map areas.

10. *Groundhog Area*

In the Groundhog area the Hazelton group is now divided into a lower and an upper part (Buckham and Latour, 1950). The lower part consists of dark-gray to black tuffs and tuffaceous sandstones interbedded with black, more or less carbonaceous shales. In places both sandstones and shales are metamorphosed to schist.

Buckham and Latour (1950) mention the presence of many plant remains in this lower part of the Hazelton group. Some poorly preserved ammonites and pelecypods collected by Muller (Geological Survey of Canada, Ottawa) may belong to *Phylloceras* and *Aucella* respectively. They show affinities to forms found in the Oxfordian of Vancouver Island.

Twenty miles south of the Groundhog field, Buckham and Latour collected some *Cardioceras* from the lower part of the Hazelton group. The age of these beds is Oxfordian.

The upper part of the Hazelton group within the Groundhog area consists of siliceous and shaly sandstones, black, yellow, brown, and purple shales, and beds of conglomerate, composed of partially rounded pebbles of dark-blue and light-green cherts. This upper part of the Hazelton group is the "Skeena series" of Malloch, a term which has now been dropped.

A Kootenay age was determined for the higher beds of this upper part of the Hazelton group by the evidence of fossil plants (Bell *in* Buckham and Latour, 1950, p. 24). At many localities pelecypods and some gastropods have been found also, but the determination of the age has not been possible.

No intrusive rocks have been reported from the Hazelton groups of the Groundhog area.

11. *Lower Stikine and Western Iskut River Areas*

The Jurassic of the lower Stikine and western Iskut River areas (Kerr, 1948a, p. 30–33, 81) consists of tuffs, graywackes, argillites, and conglomerates. A considerable part of the Jurassic seems to be of marine origin, but the presence of coaly beds indicates that some regressions of the sea may have taken place during Jurassic time. "*Porpoceras*" sp. found in the lower part of the series shows the presence of Upper Liassic. The age of the younger part of the series is doubtful because of lack of distinctive fossils.

The Jurassic rests unconformably on Upper Triassic sediments and is overlain by volcanics with some sediments, which yielded brachiopods of possibly Lower Cretaceous age.

12. *Taku River Area*

In the Taku River map area (Kerr, 1948b, p. 29–36), the Takwahoni group belongs to the Upper Liassic. It consists of argillites, sandstones, shales, conglomerates, some limestones, and dacite lavas and tuffs. The contact with the Triassic rocks is apparently unconformable. The Takwahoni group is separated from the sandstones and limestones of the overlying Sinwa formation by an unconformity. The still younger Yonakina group consists of argillites and dacite lavas and tuffs. At least one unconformity is present within this group.

Because of the lack of distinctive fossils the Jurassic age of the Sinwa formation and the Yonakina group is questionable.

13. *Dease Lake Area, Cassiar District*

The McLeod group of the Dease Lake area (Kerr, 1926, p. 86–90) consists of volcanics (breccias, tuffs, and lavas) interstratified with argillites, quartzites, and slates. Apparently no distinctive fossils have been found, so the age of this group cannot be determined in detail. The boundary between the McLeod group and the Upper Triassic Thibert group is an angular unconformity.

Younger than the McLeod group and possibly of Lower Cretaceous age is the Cassiar batholith.

14. *Salmo Area*

The Hall group of the Salmo map area, southern British Columbia, consists of argillite, sandstone, and conglomerate with minor interbedded flows and, in the upper part particularly, bands of pyroclastic rocks (Little, 1950, p. 26–28). The poorly preserved marine fossils found in the middle part of the group seem to indicate the presence of Upper Liassic

and low Middle Jurassic. The upper part of the group also contains a marine fauna. Its age is as yet indeterminable.

15. *Fernie Group Area* (Eastern British Columbia and Western Alberta)

In parts of eastern British Columbia and in western Alberta the Jurassic is known as the "Fernie group" (previously called Fernie formation or Fernie shale). This group extends from the International Boundary to about the 57th Parallel.

The term "Fernie shales" was used for the first time on the *Geological and topographical map of Crowsnest coal-fields East Kootenay District* (McEvoy and Leach, 1902). Their age was determined as "Lower Cretaceous or Jurassic." The term "Fernie shales" appears again on the map of the Blairmore-Frank coal fields (Leach, 1903) for a 700-foot series of gray and black shales. These beds were regarded as Lower Cretaceous, but later the Fernie shales of this area were placed by the same author (1912, p. 193, 194) in the Jurassic and were separated from the overlying Kootenay beds.

Since then many contributions have been made to the knowledge of the Fernie group.

No continuous section is exposed in the region which gives its name to the group, and the writer's recent investigation in the Fernie area has shown that the strata mapped as Fernie shales (McEvoy and Leach, 1902) include Triassic beds.

Much better outcrops occur in the Blairmore region, particularly on the south slope of Grassy Mountain where new roads to the coal mines have exposed an almost continuous section from the base to the top of the beds concerned.

Other almost complete sections are present at Daisy Creek (Livingstone Range), Alexander Creek (northwest of Crowsnest), Canyon Creek (Moose Mountain area), and other places, and parts of the Fernie group are exposed at many places within the whole region.

The main lines of development of the Fernie group are recognizable almost everywhere, but considerable facies changes are present.

The Fernie group has here been subdivided into lower, middle, and upper parts. These subdivisions are equivalent to the Lower, Middle, and Upper Jurassic.

The boundaries, however, are not always sharp, as the transition from the Middle Jurassic to the Callovian is gradual in many places.

Lower part of the Fernie group.—The lower part of the Fernie group consists mainly of dark shales locally with phosphate and basal conglomerate. Locally this facies has been replaced by mainly unfossiliferous sandstones—either completely, as at Grassy Mountain north of Blairmore (McLearn, 1929a, p. 83), or in part, as for example in Rock Creek near Burmis, in Daisy Creek, Livingstone Range, and in The Gap, Livingstone Range. Another facies, the so-called Nordegg member (Spivak, 1949) consisting predominantly of black limestones and calcareous shales with abundant chert fragments and locally phosphatic nodules, is well exposed in the Nordegg area and elsewhere. The name "Poker Chip Shale" has also been used for a facies of the lower part of the Fernie (Spivak, 1949).

The lower part of the Fernie group has yielded faunas of both Early and Late Liassic age (Warren, 1931; 1934; Collet, 1931; Frebold, 1951). Locally, however, the Lower Liassic is missing, and the Upper Liassic transgresses directly onto older rocks. As a consequence the lower part of the Fernie group is thicker where the Lower Liassic is developed (as in the Fernie and Crowsnest regions) than at localities where only the Upper Liassic is present (as at Rock Creek, Daisy Creek, The Gap, and in Canyon Creek in the Moose Mountain area).

The dark Lower Liassic shales of the Fernie and Crowsnest areas have yielded "*Arnioceras*," *Gryphaea rockymontana* Warren, *Pleuromya*, *Lima*, *Entolium*, *Chlamys*?, *Electryonia*, and *Pleurotomaria* (Warren, 1931). Rich in fossils is the *Oxytoma* bed, the uppermost horizon of the Nordegg member. Here *Rhynchonella*, *Terebratula*, *Ostrea*, *Oxytoma* cf. *cygnipes* Phillips, *Lima*, *Trigonia*, gastropods, and some "*Arietites*" have been found. This interesting fauna which appears to be represented also in the Fernie group of Pink Mountain, British Columbia (Hage, 1944, p. 6), has not yet been described.

The Upper Liassic is characterized by Harpoceratidae, Dactylioceratidae, *Posidonomya*, and others. The genus *Fanninoceras*, which is common in the Upper Liassic of the Queen Charlotte Islands, has not been found in the Fernie group.

Different zones of the Upper Liassic appear to be developed at various localities. For instance, in Canyon Creek, Moose Mountain area (Hume, 1932; Beach, 1943), *Harpoceras* cf. *exaratum* Young and Bird and *Dactylioceras* aff. *commune* Sowerby have been found, whereas Collet (1931, p. 17) mentions *Hammatoceras insigne* Schubler, *Dumortieria*, and many *Posidonomya bronni* Voltz from the Fiddle Creek near Jasper.

The Upper Liassic consists mostly of black shales with some intercalated hard limy bands. In places, however, as in Fiddle Creek and at Cadomin, part of the shales is replaced by sandstones.

Both the fauna and the lithologic development of the Upper Liassic of the Fernie group show similarities with that of the Upper Liassic in northwestern Europe.

The thickness of the lower part of the Fernie group is about 100 feet in the Blairmore, Daisy Creek, Rock Creek, and The Gap areas. At Fernie the thickness is about 200 feet, in Canyon Creek, Moose Mountain area, about 80 feet.

Middle part of the Fernie group.—The middle part of the Fernie group consists mainly of shales with some sandy limestone beds and lenses. A very good marker horizon is the so-called Rock Creek member (Warren, 1934) which is characterized by beds with numerous belemnoids, many ammonites, and pelecypods. It has been found almost everywhere that the Fernie group is present. Phosphate nodules and a petroliferous odor are locally characteristic of this member, which is a shallow-water deposit. Such ammonites as *Sonninia*, *Teloceras*, *Stemmatoceras*, *Defonticeras*, and *Zemistephanus* (McLearn, 1927; 1928; 1932b; Warren, 1932; 1947) indicate Middle and perhaps Late Bajocian age. The Rock Creek member is equivalent to the lower part of the Yakoun formation. Its thickness is about 40 feet.

The typical Rock Creek member has not been found in Grassy Mountain, north of Blairmore. It is probably represented by the "Lille member" of McLearn (1929a, p. 83–86). This "Lille member," which has a thickness of about 18 feet, consists of coarse sand grains cemented by lime and lies on the sandstone series. It contains the so-called *Chlamys mcconnelli* fauna. As no distinctive fossils have been found in it, no detailed age determination can be made. It has apparently the same stratigraphic position within the sequence as the Rock Creek member and may therefore be of the same age.

Above the Rock Creek member, and above the "Lille member," is a series of shales which has not yielded any guide fossils. Overlying this apparently unfossiliferous part are shales with calcareous sandstone bands, which contain McLearn's (1929a, p. 86) *Corbula munda* fauna. The lower part of these *Corbula munda* beds may be of Bathonian age, whereas its upper part, which is transitional to the so-called *Gryphaea* bed, belongs to the Callovian.

Beds probably belonging to the Bathonian occur at the headwaters of Smoky River or near Sulphur River (at 53°40′N., 118°50′W.), where *Oppelia* (*Oxycerites*) ex gr. *fallax* Guéranger et *aspidoides* Oppel were found.

Upper part of the Fernie group.—In Grassy Mountain, north of Blairmore, the *Corbula munda* beds have yielded some ammonites described by Buckman (1929, p. 6–27) as *Paracephalites*, *Metacephalites*, and *Miccocephalites* Buckman, which date the beds as Callovian. Spath, however, who thinks Buckman's genera *Miccocephalites* and *Metacephalites* belong to his genus *Arctocephalites* and that Buckman's two species of *Paracephalites* remain indeterminable macrocephalitids (Spath, 1932, p. 13, 14, 145), suggests a Late Bathonian age for these beds. More recently Warren (1947, p. 73) has expressed the opinion that *Micoccephalites* Buckman has closer affinities with the genus *Cranocephalites*, and he believes the beds are of Late Bathonian age.

It is difficult to decide about the relation of *Miccocephalites* and *Metacephalites* to other genera, as only very young stages of these forms are present. An exact age determination of the beds concerned, on the basis of these ammonites, is therefore very doubtful.

However, the present writer found some

typical *Cadoceras* in these beds which clearly indicate their age as Callovian. The remaining fauna of the *Corbula munda* beds consists mainly of pelecypods described by McLearn (1929a, p. 86). Most of the species are also present in the *Gryphaea* bed which forms the uppermost hard band of the *Corbula munda* beds. At Grassy Mountain the exposed thickness of the *Corbula munda* beds is about 90 feet.

The *Gryphaea* bed is about 5 feet thick and has been found only in the region between Daisy Creek and Carbondale River.[2]

Gryphaea impressimarginata McLearn is abundant, and the other pelecypods described by McLearn (1924) are common.

In 1950 and 1951 the writer found *Macrocephalites*, *Kamptocephalites*, *Gowericeras* or *Seymourites*, and *Perisphinctes* in this marker horizon. The *Gryphaea* bed appears to be equivalent to the "*Arcticoceras*" zone of Imlay (1948, p. 14, 15), which forms the basal part of the Rierdon and Sundance formations in the Western Interior of the United States. In northwestern Montana the conditions seem to be very similar to those in the Daisy Creek, Blairmore, and Carbondale River regions. There, also, beds filled with *Gryphaea impressimarginata* are well developed.

The ammonites found in the *Gryphaea* bed indicate its age as Early and perhaps also Middle Callovian.

Callovian ammonites have also been found at other localities. McLearn (1928, p. 20, Pl. 4, figs. 1, 2) has described *Seymourites* from Ribbon Creek, Kananaskis River; Allan and Carr (1947, p. 23) mention *Arcticoceras*, *Proplanulites*, and *Cadoceras* from the Highway-Elbow area, and a collection made by Warren in the Cascade River basin near Banff contains *Arcticoceras*, *Kamptocephalites*, and *Gowericeras*. At the last two localities and also in other places the *Gryphaea* facies seems to be entirely replaced by shaly sediments.

The "Pigeon Creek" member in the Ribbon Creek are (Crockford, 1949, p. 25, 27) is a sandstone series 120 feet thick. Its age is unknown as no distinctive fossils have been found; it is, however, younger than the Rock Creek member, and probably equivalent to the *Corbula munda* beds. The "Pigeon Creek" member is apparently also present near Banff.

In the Daisy Creek, Blairmore, and Carbondale River regions, shaly beds about 65 feet thick overlie the *Gryphaea* bed. Only a few nondistinctive pelecypods have been found.

Still higher parts of the Fernie group consist of the "Green beds" and the "Passage beds;" the latter gradually give place to the overlying Kootenay formation (McLearn, 1916, p. 111–112; 1929a, p. 87).

The glauconitic "Green beds" contain belemnoids and some gastropods. In 1951 an *Aucella* ex gr. *bronni* Lahusen was found on Carbondale River in the uppermost part of this marker horizon. At this locality the thickness is about 50 feet, at Blairmore (south of the railway tracks) it has about the same thickness, whereas on Grassy Mountain it is represented by only a few inches of strata. It is also present in Tent Mountain (Corbin area), in Alexander Creek, and in Daisy Creek. The "Green beds" seem to be restricted to certain regions, but they may be replaced by a different facies at other localities.

An exact determination of the age of the "Green beds" has not been possible. The uppermost part, which yielded *Aucella*, is younger than Callovian and belongs probably to the Oxfordian, but the lower beds may be of Callovian age. This view is supported by the occurrence of Late Callovian *Quenstedtoceras* in a rock of very similar lithology at the base of the Swift formation in Montana (Imlay, 1948, p. 16, 17).

The "Passage beds" consist of a lower, shaly and an upper, sandy part. Both the number and the thickness of the sandstone intercalations increase upward. The boundary of the Kootenay formation is usually drawn at the first massive sandstone band. These "Passage beds" have hitherto yielded belemnoids, which show the marine character of at least a great part of them; they also contain pelecypods, fish, and plant remains. An exact determination of their age has not been possible, as guide fossils have not been found. The *Cardioceras canadense*

[2] According to McLearn (1929a, p. 86) two *Gryphaea* beds are present on Carbondale River (formerly called Castle River). The writer, however, is of the opinion that, at this locality, only one *Gryphaea* bed (which was repeated by tectonics) is present.

Whiteaves (Whiteaves, 1903) from Fernie, British Columbia, may have been derived from these beds, but the matrix does not appear to agree with the rocks hitherto known to occur in the "Passage beds." Possibly, therefore, this *Cardioceras* is from a loose boulder. Another ammonite found in the Fernie group in the Red Deer River area has been considered a "*Peltoceras*" (Whiteaves, 1907, p. 80–82), which would indicate the presence of either Late Callovian or Early Oxfordian strata. This ammonite, however, is not a *Peltoceras* but a *Porpoceras* and belongs to the Upper Liassic (Frebold, 1951, p. 15–17, Pl. 11, figs. 4a, 4b).

Despite the lack of guide fossils in the "Passage beds" an approximate age determination can be made. Their lithologic character is apparently very similar to that of the Swift formation in Montana, and they may therefore be regarded as their equivalent. In the lower part of the Swift formation, directly above the zone of *Quenstedtoceras collieri*, many cardioceratids have been found, which indicates an Early Oxfordian age for the beds concerned (Imlay, 1948). This same age may be suggested for the lower part of the "Passage beds."

In the Muddy Water River region and at the headwaters of Mason Creek, specimens of Upper Jurassic *Aucella* have been found in the upper part of the Fernie group. The rocks concerned are apparently similar to those of the "Passage beds;" however, more detailed paleontological and stratigraphic investigation is needed. Such an investigation would probably solve the question of the exact age of the "Passage beds."

At Fernie, British Columbia, a very large ammonite apparently of Portlandian type has been found in the Earliest Kootenay sandstone,[3] which directly overlies the "Passage beds." This fact, and the evidence that the beds below the "Passage beds" are of Oxfordian age, supports the opinion that the "Passage beds" are Oxfordian and/or Kimmeridgian.

The contact of the Fernie group with the Kootenay formation is generally transitional. An erosional contact, however, is present at Canyon Creek in the Moose Mountain area (Hume, 1928; Beach, 1943, p. 35). In this region the rock immediately above the Fernie is called the "Moose Mountain member." This member, according to Beach (1943, p. 37), "is lithologically similar to, and occupies a like stratigraphical position to, the 'Brown sand' recognized between the Kootenay and Fernie at Turner Valley." The Moose Mountain member consists of massive beds of white to light pink-weathering coarse-grained black "bituminous" sandstone, 35 feet thick, with an unconformity at the base and top. According to Beach (1943, p. 38) the member may represent a formation distinct from either the Kootenay or the Fernie.

An unconformity between the Kootenay and Fernie may be present also in the Highwood-Elbow area (Allan and Carr, 1947, p. 27).

Bell (1944; 1946) says the flora of the Kootenay formation indicates a Lower Cretaceous age. Brown (1946), however, suggests that the plants of all or part of the Kootenay formation are indicative of a Jurassic age. In the writer's opinion only the earliest part of the Kootenay, which yielded the large ammonite, belongs to the Jurassic.

Farther north, the Nikanassin formation at Mountain Park near Jasper, and the Dunlevy formation in the Pine and Peace River valleys—both equivalents of the Canadian Kootenay formation—contain *Aucella* in their basal parts. These are possibly of Jurassic age (McLearn, 1945, p. 2, 10), and the beds in which they have been found may be equivalents of the Early Kootenay sandstone at Fernie.

The "Passage beds" show a very uniform development in certain parts of the Foothill region and are easily recognizable. The thickness is, however, somewhat variable. Thus, 204 feet was measured in Grassy Mountain, north of Blairmore, 147 feet in Daisy Creek, Livingstone Range, and 106 feet in Canyon Creek, Moose Mountain area.

In the Sikanni Chief River valley, British Columbia, the Fernie group is thin and seems to include only beds of Lower Jurassic age. "*Arnioceras*," *Gryphaea*, *Pecten*, *Oxytoma* cf. *cygnipes* Young and Bird, and *Rhynchonella*

[3] Warren (1951, p. 7) also believes the Earliest Kootenay sandstone belongs to the Upper Jurassic. He suggested an Oxfordian age, but the new ammonite from Fernie shows that the sandstone actually is of Portlandian age.

have been reported from this region (Hage, 1944, p. 6). A little farther north the Fernie group appears to be absent (Williams, 1944, p. 23).

In the Pine River and Peace River valleys, British Columbia, the Jurassic has been described as Pine River formation (Spieker, 1922, p. 112–126). Warren (1934), p. 63) pointed out that there is little doubt that the Pine River formation is lithologically and stratigraphically the northern continuation of the Fernie group, and the term Fernie group is now used for these beds (McLearn and Kindle, 1951, p. 60). They contain poorly preserved ammonites of "*Arnioceras*" type, which indicate the presence of at least the lower part of the Lower Jurassic in this region.

The variation in total thickness of the Fernie group is shown by the following examples: Daisy Creek (Livingstone Range) 550–600 feet, Canyon Creek (Moose Mtn. area) 220 feet, Ribbon Creek area 1095 feet.

16. *Yukon*

The Laberge series which has a thickness of about 9000 feet has yielded ammonites of Lower Jurassic and perhaps Middle Jurassic age. In the Laberge map area (Bostock and Lees, 1938, p. 15; Lees, 1934) a Lower Liassic fauna with "*Psiloceras*" and *Arnioceras* was found in the lower part of the series. At the Five-finger Rapid, in the Carmacks district (Cockfield and Bell, 1926, p. 21; 1944, p. 6; Bostock, 1936, p. 27), the Middle Liassic is indicated by *Prodactylioceras* and *Amaltheus*, and the Upper Liassic by *Pseudogrammoceras* cf. *fallaciosum* Bayle and *Dumortieria*. Other forms mentioned by Buckman (*in* Cockfield and Bell, 1926, p. 21) are very poorly preserved, and stratigraphic conclusions cannot be made. The presence of lower Middle Jurassic is not certain, although there are some questionable ammonites which may belong to *Pleydellia*.

The age of the upper part of the series is unknown but may be Jurassic (Bostock, 1936).

The Tantalus formation, which apparently overlies the Laberge series conformably, contains fossil plants of Lower Cretaceous age according to Bell (*in* Cockfield and Bell, 1944, p. 7).

Middle and Upper Liassic ammonites (*Amaltheus* and *Dumortieria* respectively) are also present in the Laberge series of the Bennett area in the border region of Yukon and British Columbia.

In the section of the Firth River, northern Yukon, Cadoceratidae seem to be common and suggest the presence of the Callovian. Buckman (*in* O'Neill, 1924, p. 14–15) states that in general the agreement of the Canadian forms is with those obtained from Franz Josef Land and not with the species from Alaska. More recent collections, made in the Richardson Mountains, also show the presence of Callovian. A collection of ammonites made on Porcupine River between Bell and Old Crow rivers and determined by Warren and Imlay (Personal Communication by Warren) contains some species of *Arctocephalites* and a questionable *Arcticoceras*. Thus the presence of Callovian and perhaps Late Bathonian is indicated in this region. At Black Mountain, on the west side of the Mackenzie River delta, a fauna with *Aucella* of probable Upper Jurassic age has been found (Stanton *in* O'Neill, 1924, p. 17). Upper Jurassic rocks, younger than Callovian, may also be present in the Richardson Mountains. Here the Lower Cretaceous is characterized by marine sediments with *Aucella* (Personal Communication by Jeletzky).

17. *Prince Patrick Island*

An ammonite found at Point Wilkie on Prince Patrick Island was described as *Ammonites m'clintocki* Haughton (1858, p. 244, 245, Pl. 9, figs. 2–4). Neumayr (1885, p. 38, 141, Pl. 1, figs. 5–8), who refigured this ammonite, compared it with some varieties of *Ludwigia murchisonae* and other related forms. The state of preservation of Haughton's species is too poor for an exact age determination (Frebold, 1945, p. 264, 265), but it probably belongs to the basal part of the Middle Jurassic.

Another collection from Prince Patrick Island was made in 1949 by MacDonald (National Museum of Canada, Ottawa) at Bay Cliff, about 1 mile northwest of Mould Bay station. It contains indeterminable ammonites, which may indicate the presence of other Jurassic rocks, in addition to those characterized by "*Harpoceras*" *m'clintocki* Haughton.

According to Jeletzky (Personal Communica-

tion) marine Lower Cretaceous with *Aucella* and belemnoids is exposed on the island.

18. *Southern Plains of Alberta*

In the southern Alberta Plains the Jurassic is known only from the subsurface. Its development is similar to the Ellis group of Montana which is subdivided into the Sawtooth, Rierdon, and Swift formations (Weir, 1949).

In southern Alberta the Sawtooth formation lies unconformably on limestone of Mississippian age. Its basal member is the Crow Indian Lake sandstone, 15 to 20 feet thick, which is overlain by the median shale member, 12 to 14 feet thick. The upper part of the formation consists of the oil-producing Conrad sandstone member, 1 to 30 feet thick, with 1 to 3 feet of green shaly sand or sandy shale containing many belemnoids, *Gryphaea*, *Ostrea*, and chert pebbles on top.

The Rierdon formation is a greenish-gray or dull olive-green calcareous shale with some argillaceous limestone beds. Belemnoids and *Gryphaea* have been found. Only in the southernmost part, where the Swift formation has not been removed, is the original thickness still preserved.

At the base of the Swift formation a very glauconitic horizon with chert pebbles is developed. This is followed by a dark-gray, noncalcareous shale overlain by a "Ribbon type" sandstone member.

The Swift formation rests disconformably on the Rierdon formation.

In many places part or all of the Swift formation has been removed by pre-Blairmore erosion, and the Blairmore formation rests locally on the shale of the Rierdon formation. The Jurassic formations thin from south to north. In the south the Blairmore formation lies on the upper part of the Swift formation.

In Montana the determination of the age of the three formations of the Ellis group has been possible on the basis of guide fossils (Imlay, *et al.*, 1948; Imlay, 1948). According to these authors the lower part of the Sawtooth formation belongs to the Bajocian (at any rate partly equivalent to the Rock Creek member of the Fernie group) and its upper part to the "*Arctocephalites*" beds (the *Corbula munda* fauna of the Fernie group). The Rierdon formation, which in Montana contains *Arcticoceras*, *Gowericeras*, and *Kepplerites*, is placed in the Callovian, and the Swift formation with *Quenstedtoceras* and *Cardioceras* in the uppermost Callovian and Oxfordian respectively.

Because of the very similar or identical lithologic development of the Ellis group in southern Alberta, the corresponding formations probably are approximately the same age as the near-by occurrences in Montana.

The Ellis group of southern Alberta shows also a development very similar to the Fernie group. This is particularly true of the upper part of both groups, the Swift formation of southern Alberta and the "Passage beds" of the Fernie group. In both cases the sequence begins with a glauconitic zone at the base, followed by shale which gradually gives place to sandstones with shale intercalations.

The presence of many belemnoids and *Gryphaea* at the top of the Sawtooth formation is reminiscent of the development of the *Gryphaea* beds of the Fernie group. As these faunal elements are not numerous in the *Corbula munda* fauna a correlation of the uppermost part of the Sawtooth formation with a part of the *Gryphaea* beds of the Blairmore region and its surroundings may be supposed.

19.–20. *Southern Plains of Saskatchewan and Southwestern Manitoba*

The Jurassic of Saskatchewan (Wickenden, 1932; 1933; Fraser *et al.*, 1935, p. 11–13) is known only from deep wells. It consists mainly of marine gray shale with some limestone and sandstones. In the upper part of the sequence a marine zone of shale and some limestone is developed. It contains Foraminifera which, according to Wickenden (1933, p. 157), are very similar to those from the Sundance formation in southeastern Montana. The species are found mostly in the Middle and Upper Jurassic of Europe. Another marine fauna, from the Avonlea well, contains macrocephalitids and is probably equivalent to the *Corbula munda* fauna of the Blairmore area (Fraser *et al.*, 1935, p. 12). Below this marine horizon nonmarine sediments with many specimens of fossil *Chara* fruit and smooth ostracods are present. These in turn rest on apparently marine beds containing *Astarte* and other megafossils and *Guttulina*.

In the Commonwealth Manitou No. 2 well,

southern Manitoba, the Jurassic sequence consists of an upper marine, a middle nonmarine (with *Chara* fruit and smooth ostracods), and a lower marine member (Wickenden, 1945, p. 9, 65; Kerr, 1949, p. 18–21).

Farther north, in the Neepawa well, the same subdivision—two marine and a middle nonmarine member—is present (Wickenden, 1945, p. 10), but the thickness is less than in the Manitou No. 2 well. In the Dauphin well, about 65 miles farther northwest, all three members are present. Here, however, the thickness of the whole sequence, which in Manitou No. 2 well is about 425 feet, has decreased to 170 feet.

The sediments in the upper part are mostly gray shales with some limestone and sandstone; in the lower part variegated shale with limestone and gypsum at the base is predominant. The nonmarine member forms the top of the variegated shale.

Determination of the age of the Jurassic rocks of southern Saskatchewan and Manitoba is difficult owing to the lack of guide fossils. Only the presence of beds of Late Bathonian or Early Callovian age (equivalents of the Fernie *Corbula munda* fauna) seems to be certain.

According to Imlay (Personal Communication) the lithologic characteristics and stratigraphic position of the variegated beds in the lower part of the sequence suggest a northern extension of the Middle Jurassic Piper formation of Montana and North Dakota. The Amaranth formation, which lies directly below the definite marine Jurassic in Manitoba (Wickenden, 1945, p. 8, 9, 65, 70, 71), may possibly belong to the Jurassic according to Imlay (Personal Communication) and may be equivalent to the type Gypsum Spring formation of central Wyoming.

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INDEX TO STRATIGRAPHIC NAMES

Jurassic units—capital letters—PARSON BAY FM.
Units of doubtful age—italics—*Parson Bay fm.*
Non-Jurassic units—roman type—Parson Bay fm.
Names discarded—D
Abbreviations: fm., formation; gr., group; mem., member; ser., series; sh., shale; ss., sandstone

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ASHCROFT SER. 1233
BILLHOOK FM. 1232, Pl. 1, col. 4
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Plate 1. Correlation of the Jurassic formations of Canada.